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SPECIFICATION

No. LSP-310-2 Date: 5-7-63

LUNAR EXCURSION MODULE

PROPELLANT SYSTEM AND THRUST CHAMBER ASSEMBLIES

REACTION CONTROL SUBSYSTEM

DESIGN CONTROL SPECIFICATION FOR [U]

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(NASA-CR-117603) DESIGN CONTROL SPECIFICATION FOR LUNAR EXCURSION MODULE PROPELLANT SYSTEM AND THRUST CHAMBER ASSEMBLIES REACTION CONTROL SUBSYSTEM (Grumman Aircraft Engineering Corp.) 106 p 00/20

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GRUMMAN AIRCRAFT ENGINEERING CORPORATION
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PROPELLANT SYSTEM AND THRUST CHAMBER ASSEMBLIES

REACTION CONTROL SUBSYSTEM,

LUNAR EXCURSION MODULE APOLLO SPACECRAFT

1. SCOPE

1.1 Scope. - This specification outlines the requirements for the Propellant System and Thrust Chamber Assemblies (PS/TCA) to be used on the bipropellant Reaction Control System of the Lunar Excursion Module (LEM), Apollo Spacecraft.

1.2 Classification. - The Propellant System and Thrust Chamber Assemblies as shown schematically in Figure I shall consist of:

(a) Sixteen (16) radiation cooled thrust chamber assemblies. Each assembly shall consist of a thrust chamber with fuel and oxidizer solenoid valves (thrust chamber valves). The thrust chamber assemblies are grouped in clusters of four and externally mounted on the LEM vehicle.

(b) Propellant control components, including; fill and vent disconnect couplings, burst discs, filters, and solenoid shutoff valves.

(c) Two oxidizer and two fuel tanks with positive expulsion bladders.

(d) Instrumentation as required.

NOTE: All propellant lines external to component packages as specified in Specification Control Drawing LSC-310-100 (Figure 6) wiring harness and crossfeed valves will be provided by Grumman.

2. APPLICABLE DOCUMENTS

2.1 General. - The following documents of the issue in effect January 14, 1963 form a part of this specification only to the extent specified herein:

SPECIFICATIONS

Military

MIL-B-5087	Bonding; Electrical (for Aircraft)
MIL-S-7742	Screw Threads, Standard, Optimum Selected Series, General Specification for
MIL-P-26539	Propellant, Nitrogen Tetroxide
MIL-P-27402	Propellant, Hydrazine, Unsymmetrical Dimethyl Hydrazine

STANDARDS

Military

MIL-STD-130	Identification Marking of U.S. Military Property Internal Threads
MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
MIL-STD-704	Electrical Power, Aircraft, Characteristics and Use of
MIL-STD-810	Environmental Test Methods for Aerospace and Ground Equipment

Grumman Documents

LSP-14-2	Electromagnetic Interference, General Specification for

2.1 (Continued)

Drawings

LSC-310-100 Specification Control Drawing

2.2 Precedence. - When the requirements of the Purchase Order, this specification and subsidiary specifications, are in conflict, the following precedence shall apply:

(a) Purchase Order - The purchase order shall have precedence over any specifications.

(b) This Specification - This specification shall have precedence over all subsidiary specifications.

2.3 Availability of Documents. - Copies of this specification and other applicable documents referenced herein may be obtained upon request from LEM Program Data Management, Grumman Aircraft Engineering Corporation, Bethpage, Long Island, New York, Attention: Specifications Group.

3. REQUIREMENTS

3.1 General. -

3.1.1 Drawings and Data Submittal. - All drawings and other data generated under this specification shall be submitted in accordance with the purchase order.

3.1.2 Deviations. - When the requirements of this specification and any applicable subsidiary specifications cannot be met the following shall apply:

(a) Deviations shall be noted in the vendor's proposal documents and brought to the attention of Grumman.

(b) Deviations shall require approval by Grumman Engineering prior to incorporation into any component.

3.1.2 (Continued)

(c) Parts containing unauthorized deviations shall be subject to rejection.

3.1.3 Mock-up. - A full scale metal mock-up of all components shall be provided for assembly at Grumman. Used components or actual component housings shall be used wherever possible. The mock-up shall be kept current with approved changes throughout the contract, unless otherwise authorized by Grumman.

3.2 Performance. -

3.2.1 Operating. - The Propellant System and Thrust Chamber Assemblies (PS/TCA) when pressurized per 3.4.4, shall operate within the performance limits specified in the following paragraphs during and after exposure to the combined environmental and load conditions specified in Table II.

3.2.1.1 Ratings. - The PS/TCA nominal vacuum performance ratings shall be as defined in Table I.

3.2.1.2 Repeatability. - Repeatability of thrust level and minimum impulse bit for a given thrust chamber and between individual thrust chambers comprising the (PS/TCA), shall be within the tolerances specified in Table I.

3.2.1.3 Attitudes. - The (PS/TCA) when pressurized per 3.4.4 shall start, operate as required and shutdown in any attitude under the flight maneuver loads and conditions specified herein, and under zero gravity conditions.

3.2.1.4 Ascent Interconnect. - The PS/TCA shall meet all the requirements of this specification when supplied with propellants from the LEM Ascent Stage Propulsion System. These propellants conform to the requirements of paragraphs 3.4.1.1 and 3.4.1.2 and will be supplied at a temperature of $70^{\circ}F \pm 30^{\circ}$ and a nominal static pressure

3.2.1.4 (Continued)

of 188 ± 5 psig. Maximum dynamic pressure loss across the interconnect components will not exceed 5 psi.

3.2.1.5 Malfunction. - The PS/TCA when supplied with specific propellants and pressurized in accordance with 3.4.4 shall, under any single condition of malfunction, start, operate, shutdown and restart in a stable, safe and reliable manner, or shutdown without presenting a hazardous condition that could cause damage to the PS/TCA vehicle or occupants. Malfunction conditions shall include, but not be limited to such events as electrical system failure, excessive voltage or frequency fluctuations, severe combustion instability, fuel or oxidizer leads, operation at OFF O/F design ratios, and propellants which do not conform to the requirements of 3.4.1.1 and 3.4.1.2 herein. A malfunction analysis shall be performed by the vendor early in the development program. A malfunction analysis report shall be submitted in accordance with the purchase order.

3.2.1.6 Duty Cycle. - The nominal duty cycle shall be as shown in Table III.

3.2.2 Life. -

3.2.2.1 Operating Life. - The PS/TCA shall be capable of accomplishing the nominal mission duty cycle (Table III) at any time within a period of 14 days under the environmental and load conditions specified in Table II, Part (c). During the pre-launch period, the PS/TCA shall be serviced and tested in accordance with approved procedures and shall require no additional servicing during the 14 days operational period.

3.2.2.2 Thrust Chamber Operating Life. - Each thrust chamber shall have a minimum operating life as shown in Table I following final acceptance test at the vendor's facility.

3.2.2.3 Storage Life. - The PS/TCA shall be capable of operating as required after being subjected to permanent storage for five years with necessary periodic maintenance. Storage life is a design criterion only and does not require demonstration. No permanent weight shall be added to the PS/TCA to meet these requirements.

3.2.2.4 Frequency of Operation. - Satisfactory operation shall be required after a non-operating period of 2 years under the environment conditions of Table II, Part (a), following acceptance tests.

3.3 Design. -

3.3.1 General. - The PS/TCA shall be designed to meet the environmental and load criteria of Table II, in addition to the self generating loads incurred in meeting the specified performance. Design load envelopes shall be established by superposition of rationally deduced critical loads for all ground and operational conditions and shall include cumulative effects, as well as simultaneous loadings.

3.3.1.1 Safety Factor. - Factors of safety must be applied to the levels of Table II as well as to the self-generated loads of the PS/TCA. Rational allowance shall be made and incorporated in these loads for stress concentrations, fatigue loading and dynamic response. For steady loads or accelerations and for shock loading, the ultimate factor of safety is 1.5. For vibratory loads the ultimate factor of safety for g or D.A. is 1.3, g^2/cps is $(1.3)^2$. For pressure vessels, when pressure is applied as a singular load, the proof factor is 1.33 and the factor is 1.5. For pressurized units such as the control valves and valve actuators, the proof factor is 2.00 and the ultimate factor is 3.00. For combined loadings, the ultimate factor of safety is 1.5 except that when pressure effects are relieving, pressure shall not be used.

3.3.1.1.1 Vibration Amplification Factor. - The PS/TCA shall suffer no detrimental effects when exposed to the input vibration conditions specified on Table II. For design, the environmental condition on Table II shall be multiplied by the appropriate factors specified in paragraph 3.3.1.1.

3.3.1.1.1 (Continued)

The vibrational motion amplification factor on any portion of the equipment shall be limited to a maximum of 10 where not already limited to a lower value by other design requirements. This amplification factor is defined as the total displacement of any point on the item under test divided by the displacement of the input device. This criteria shall be substantiated during development testing. In cases where this requirement appears difficult to accomplish, Grumman shall be consulted for direction before proceeding with the design development.

3.3.1.2 Dry Weight. -

(a) The vendor shall endeavor to produce the lightest practical Propellant System and Thrust Chamber Assemblies capable of meeting the requirements of this specification.

(b) The specification maximum dry weight shall be as shown in Table IX.

(c) The vendor shall establish and maintain a weight control program as outlined in the purchase order to insure that the maximum weight is not exceeded.

3.3.1.3 Moment of Inertia and Center of Gravity. - The vendor shall determine the center of gravity location and moments of inertia of all components and assemblies.

3.3.1.4 Overall Dimensions. - The overall dimensions of the PS/TCA components shall not exceed the space envelope as specified in Specification Control Drawing LSC-310-100 (Figure 6).

3.3.1.5 Contamination. - The PS/TCA shall be designed to operate and meet all the requirements of this specification with a contaminant level that may result from the propellants of 3.4 and the environment encountered during assembly, disassembly and packaging for shipment.

3.3.1.6 Interchangeability. - The following components shall be designed for physical and functional interchangeability (in accordance with the definition of Section 6).

(a) Thrust chamber assemblies

(b) Thrust chamber cluster assemblies (4 thrust chamber assemblies)

(c) Propellant section control components as specified in 3.3.2.3.

(d) Propellant tanks

NOTE - If above components are connected by a brazing technique they are defined as replaceable in accordance with the definition of section 6.

3.3.2 Components. -

3.3.2.1 Thrust Chamber Assemblies. - Radiation cooled thrust chambers shall be assembled in clusters of four (4) each as shown on Specification Control Drawing LSC-310-100. Each thrust chamber shall include two separate, normally closed, solenoid actuated valves, one for the fuel and one for the oxidizer.

3.3.2.1.1 Shielding and Insulation. - It shall be the vendor's responsibility to provide shielding and thermal insulation of the clusters as mounted on the LEM vehicle, to insure adequate thrust chamber operation under the environments specified in Table II.

3.3.2.1.2 Limiting Zone Temperature. - The thrust chamber assembly shall be designed to meet the performance requirements of this specification with an increase in propellant temperature upstream of the thrust chamber propellant valves as a result of thrust chamber operation or post-run heat soak-back.

3.3.2.1.3 Pressure. - At the operating temperature, the thrust chamber assembly shall be capable of withstanding the proof pressure without yielding, leaking or malfunctioning and shall withstand the ultimate pressure without structural failure.

* (a) Design pressure to be determined by vendor.

* (b) Proof pressure to be determined by vendor.

* (c) Ultimate pressure to be determined by vendor.

3.3.2.2 Propellant Tankage. - The propellant system shall incorporate two oxidizer tanks and two fuel tanks conforming to Specification Control Drawing LSC-310-100. Tank materials shall be selected to provide maximum compatibility with the specified propellants and helium pressurant or mixtures thereof and shall be subject to Grumman approval.

3.3.2.2.1 Bladders. - Bladders shall be incorporated in all propellant tanks for positive expulsion and shall be capable of 50 cycles through a propellant temperature range of +40°F to +100°F. The effect of cold helium pressurant shall be taken into consideration. Bladder materials shall be selected for minimum permeability, and maximum compatibility with the specified propellants and helium pressurant or mixtures thereof and shall be subject to Grumman approval.

3.3.2.2.1.1 Differential Pressure. - The bladder and port design shall be such that neither 200 psig in the propellant compartment with zero psig at the helium inlet, nor 200 psig helium pressure with zero psig at the propellant outlet' will cause expulsion device failure or damage.

3.3.2.2.2 Capacity. - The total usable capacity of the propellant ranks shall be as specified in Table I.

3.3.2.2.3 Expansion Space. - The volume of the propellant compartment with the bladder installed shall provide for the capacity as specified in 3.3.2.2.2 above, at a temperature of 65°F and 30 psig and an expansion space that permits a propellant temperature rise to 100°F without opening the burst disc.

* To be determined by vendor.

3.3.2.2.4 Pressure. - The nominal tank pressure shall be 181 ± 4 psig. Each tank shall be designed for a maximum expected operating pressure (MEOP) of 250 psig and shall withstand propellant fill preparation pressure of 28.0 inches of mercury at the propellant port with the helium port vented.

3.3.2.2.5 Factor of Safety. - The tank proof pressure shall be 1.33 times the MEOP. The ultimate pressure shall be 1.5 times the MEOP.

3.3.2.2.6 Endurance Cycling. - The tank shall be designed to withstand 3000 pressure cycles from zero to nominal tank pressure to zero.

3.3.2.3 Propellant Section Control Components. - The propellant section control components types shall be as follows (See Figure 1):

(a) Propellant fill and vent disconnect couplings

(b) Burst disc assemblies

(c) Filters

(d) Main Propellant Shut-off valves (solenoid-latching type)

(e) Thrust Chamber Assembly Isolation valves (solenoid-latching type)

(f) Ground test points and instrumentation as required in 3.3.4.

3.3.2.3.1 Pressure. - Each pressurized component shall be capable of withstanding the proof pressure without yielding or leaking and shall withstand the ultimate pressure without structural failure.

3.3.2.3.1 (Continued)

(a) Proof pressure 2.00 times the MEOP.

(b) Ultimate pressure 3.00 times the MEOP.

3.3.2.3.2 Propellant Lines. - All propellant lines external to component packages as specified in Specification Control Drawing LSC-310-100 will be furnished by Grumman. Flow characteristics of these lines will be provided by Grumman.

3.3.3 Electrical. -

3.3.3.1 Electrical Power. - Electrical power will be supplied to all components (main propellant shut-off valves, thrust chamber isolation valves, thrust chamber cluster assemblies) by Grumman.

3.3.3.1.1 Voltage. - All components shall meet the requirements of this specification when operating within the voltage range of 24 to 32 volts d-c.

3.3.3.1.2 Emergency Voltage. - All components shall be capable of emergency operation with the voltage range of 20 to 32 volts d-c.

3.3.3.1.3 Power Requirements. -

* (a) The total electrical power input to each main propellant shut-off valve shall not exceed * ____________ watts.

* (b) The total power input to each set of four (4) thrust chamber isolation valves shall not exceed * ____________ watts.

* (c) The total power input to each thrust chamber cluster assembly shall not exceed * ____________ watts.

*To be supplied by the vendor

3.3.3.1.3 (Continued)

(d) The power requirements for operation of the above units shall be established by the vendor. A power utilization analysis shall be performed by the vendor. This analysis shall take into consideration power consumption, reliability, weight, design, performance and electromagnetic interference. The analysis along with completed Form LSK-390-1027 shall be submitted to Grumman for approval. When approved the power requirements shall become a part of this specification. Data shall be submitted in accordance with LVR-310-2, Section E.

3.3.3.2 Electrical Circuit Design. - The electrical circuit design including instrumentation shall meet the performance and design requirements of this specification.

(a) Electrical bonding shall be provided in accordance with MIL-B-5087.

(b) An electrical return wire shall be utilized in all electrical components forming part of the PS/TCA.

(c) All electrical elements shall be electrically isolated from their housings.

3.3.3.2.1 Electromagnetic Interference. - No component shall cause electromagnetic interference beyond the limits specified in Specification LSP-14-2.

3.3.3.2.2 Electrical Component Design. - All electrical components including instrumentation shall be designed for the service and the environmental conditions (in 3.5 and Table II) of this specification.

3.3.3.2.3 Dielectric Strength. - Electrical components excluding instrumentation shall withstand without electrical breakdown a dielectric voltage in accordance with MIL-STD-202, Method 301, except that the details shall be specified in the individual component specification.

3.3.3.2.4 Insulation Resistance. - Electrical components excluding instrumentation shall maintain a minimum isolation resistance in accordance with MIL-STD-202, Method 302, the details of which shall be specified in the individual component specification.

3.3.3.2.5 Ignition Proof. - Electrical components including instrumentation or operation of same shall not ignite any explosive mixture surrounding the PS/TCA (i.e., hydrogen and oxygen).

3.3.3.2.6 Fail-Safe Provisions. - Failure of electrically operated components forming part of the PS/TCA shall not propagate sequentially. Design shall fail safe.

3.3.3.3 Electrical Wiring. - The installation of wiring and wiring devices used for the electrical components in the PS/TCA shall meet the functional and environmental requirements as set forth by this specification.

3.3.3.3.1 Wiring Internal to PS/TCA Units (Clusters and Components). - Internal wiring shall be installed to:

(a) Provide accessibility for inspection and maintenance.

(b) Minimize the possibility of damage.

(c) Prevent chafing and provide protection when wires or cables are routed.

(d) Provide separation of wires or cables from lines containing propellants.

(e) Minimize the radius of bend to ten (10) time the outside diameter of the cable or wire.

(f) Minimize excessive slack.

(g) Effectively eliminate electromagnetic interference to the limits specified in Specification LSP-14-2.

3.3.3.3.1 (Continued)

(h) Secure wires and cables when routed through structural members.

(i) Prevent mechanical strain that would tend to break the conductors and/or the connections.

(j) Wires and cables shall be supported at suitable intervals to prevent excessive movement under all vibration conditions.

3.3.3.4 Electrical Connections. - Wiring from each component shall pigtail from the component to a connector.

3.3.3.4.1 Component Connection. - Electrical connections within each component shall be welded, brazed or soldered.

3.3.3.4.2 PS/TCA Components and Cluster Wire Connections. -

* 3.3.3.4.2.1 Main Propellant Shut-Off Valve. - Wires from the main propellant shut-off valves shall be pigtailed to a length of ____________________* feet. (Length and end preparation shall be specified by Grumman at a later date.)

3.3.3.4.2.2 Thrust Chamber Isolation Valves (Set of Four). - Wires from the components contained within this unit shall be brought out to two connectors. Wires associated with one fuel and one oxidizer valve shall be brought out through one connector and wires associated with the remaining fuel and oxidizer valves shall be brought out through the second connector (this is a typical arrangement for all four units). Location and type of connector shall be specified by Grumman at a later date.

*To be supplied by the vendor

3.3.3.4.2.3 Thrust Chamber Cluster Assembly. - Wires from the Thrust Chamber Assemblies contained within this cluster shall be brought out to two connectors. Wires associated with two (2) thrust chamber assemblies shall be brought out through one connector and wires associated with the remaining two (2) thrust chamber assemblies shall be brought out through the second connector. (This is a typical arrangement for all four (4) clusters, (Ref. Figure 3)). Location and type of connector shall be specified by Grumman at a later date.

3.3.3.5 Wires and Cables. - The wire and cable used shall be suitable for continuous operation at 600 volts rms maximum at the environments specified in Table II.

3.3.3.6 Instrumentation Wiring. - Instrumentation wiring shall be separate from the functional wiring and shall be specified by Grumman at a later date.

3.3.3.7 Thermal Design. - A prime consideration in the design of all electrical and electrically operated devices shall be the thermal effect of a space vacuum on rated and overload characteristics of electrical devices. The vendor shall conduct an analysis of these characteristics.

3.3.4 Instrumentation. - Instrumentation components shall be provided subject to the approval of Grumman to monitor the performance of the equipment during all phases of its test and operation. The sensors and signal conditioning equipment selected for each application shall have an inherent reliability greater than the measured and measuring subsystem and shall be compensated such that the capability to perform the intended function is not degraded by the environmental conditions to which they are subjected.

3.3.4.1 Excitation Voltage. - Excitation voltage, where required, shall be standardized to the values specified by Grumman.

3.3.4.2 Inaccessible Areas. - Location of sensors in inaccessible areas is to be avoided. If a sensor must be located in an inaccessible area, a space sensor shall also be installed.

3.3.4.3 R & D (Flight Test) Measurements. - Additional pick-up points shall be required for R & D (Flight Test) Instrumentation to be specified by Grumman.

3.3.4.4 Classification. - Instrumentation including but not limited to those for measurements specified in Table IV and is shown in the "Instrumentation Schematic" (Figure 2) shall be provided and installed. The measurements specified in Table IV and Figure 2 have been categorized into the following classes:

3.3.4.4.1 Group IV. - The vendor shall provide the pick-up points, transducers, signal conditioners and panel indicators. Whenever possible and desirable, standard qualified instrumentation and indicators shall be used. The vendor shall provide a pick-off for telemetry purposes with the following characteristics.

3.3.4.4.1.1 Analog Channels. - Analog pick-offs shall provide either a 0-5 volt d-c (high level) single ended output or a 0-250 m volt d-c (low level) unipolar, differential output. The output impedance of both levels shall be 5000 ohms or less.

3.3.4.4.1.2 Digital Channels. - The OPS will be capable of accepting parallel digital data. Digital output voltage levels shall be as follows:

(a) Binary "1" 3.5 to 10 volt d-c

(b) Binary "0" 0 ± 0.5 volt d-c

The source impedance of all digital channels shall be 5000 ohms or less.

3.3.4.4.1.3 Calibration. - Vendor shall calibrate all instrumentation and indicators at reasonable intervals with equipment traceable to the National Bureau of Standards. Calibration procedures and equipment approved by Grumman shall be used. Vendor shall supply provisions for in-flight calibration which are compatible with the LEM calibration scheme.

3.3.4.4.1.4 Fail-Safe Provisions. - Vendor shall design instrumentation and indicators such that any failure shall not cause damage to telemetry equipment, to interface equipment or to vendor equipment. There shall be no coupling between the panel indicator and telemetry channel which could result in cross effects between the two, even in the event of malfunction.

3.3.4.4.2 Group III. - The vendor shall provide the pick-up points, transducers and signal conditioners. Wherever possible and desirable, qualified LEM instrumentation shall be used.

3.3.4.4.2.1 Analog Channels. - Analog transducers and signal conditioners shall provide either a 0-5 volt d-c (high level) single ended output or a 0-250 m volt d-c (low level) unipolar, differential output. The output impedance of both levels shall be 5000 ohms or less.

3.3.4.4.2.2 Digital Channels. - The OPS will be capable of accepting parallel digital data. Digital output voltage levels shall be as follows:

(a) Binary "1" 3.5 to 10 volt d-c

(b) Binary "0" 0 ± 0.5 volt d-c

The source impedance of all digital channels shall be 5000 ohms or less.

3.3.4.4.2.3 Calibration. - Vendor shall calibrate all instrumentation at reasonable intervals with equipment traceable to the National Bureau of Standards. Calibration procedures and

3.3.4.4.2.3 (Continued)

equipment approved by Grumman shall be used. Vendor shall supply provisions for in-flight calibration which are compatible with the LEM calibration scheme.

3.3.4.4.2.4 Fail-Safe Provisions. - Vendor shall design instrumentation such that any failure shall not cause damage to telemetry equipment, to interface equipment, or to vendor equipment.

3.3.4.4.3 Group II. - The vendor shall provide the pick-up point and transducers.

3.3.4.4.3.1 Transducers. - The transducers shall provide an analog or digital output compatible with the appropriate LEM signal conditioning equipment. Whenever possible and desirable, standard qualified transducers shall be used.

3.3.4.4.3.2 Calibration. - Vendor shall calibrate all transducers at reasonable intervals with equipment traceable to the National Bureau of Standards. Calibration procedures and equipment approved by Grumman shall be used. Vendor shall supply provisions for in-flight calibration which are compatible with LEM calibration scheme.

3.3.4.4.3.3 Fail-Safe Provisions. - Vendor shall select transducers such that any failure shall not cause damage to vendor equipment.

3.3.4.4.4 Group IB. - The vendor shall provide pick-up points and environmental characteristics for all measurements.

3.3.5 Control. - Thrust control shall be provided for in the following manner.

3.3.5.1 Thrust Chamber Valve Power Coil. - Each thrust chamber valve shall incorporate a solenoid having a power coil with the following characteristics at ambient temperatures ($70^{\circ}F \pm 15^{\circ}F$):

3.3.5.1 (Continued)

* (a) Pull-in current * amp

* (b) Coil resistance * ohm

* (c) Coil inductance * henry

* (d) Time to reach 90% of rated thrust is * seconds after application of a * volt step.

3.3.5.2 Thrust Chamber Valve Emergency Coil. - Each thrust chamber valve shall also incorporate a solenoid having an emergency coil with the following characteristics at ambient temperatures ($70^\circ F \pm 15^\circ F$):

* (a) Pull-in current * amp

* (b) Coil resistance * ohm

* (c) Coil inductance * henry

* (d) Time to reach 90% of rated thrust is * seconds after application of a * volt step.

3.4 Propellants and Fluids. -

3.4.1 Propellants. -

3.4.1.1 Fuel. - The fuel shall be a mixture of 50% hydrazine (N_2H_4) and 50% unsymmetrical dimethylhydrazine (UDMH) conforming to MIL-P-27402.

3.4.1.2 Oxidizer. - The oxidizer shall be nitrogen tetroxide (N_2O_4) conforming to MIL-P-26539.

3.4.2 Mixture Ratio. - The oxidizer to fuel mixture ratio by weight shall be as specified in Table I.

*To be supplied by the vendor

3.4.3 Temperature. - Propellant temperature shall be as specified in Table II.

3.4.4 Pressurant. - Helium gas will be supplied to the inlet ports of the propellant tanks at a pressure of 181 psia $\pm$ 4.

3.4.5 Leakage. - Internal leakage of the system fluids under operating and non-operating pressures which would impair or endanger system operation shall not be permitted. External leakage of propellants shall not be permitted under operating and non-operating pressures either during ground checkout or operation. Leakage across thrust chamber valve poppet seat shall not exceed 5 cc/hr of standard nitrogen when the nitrogen is applied to the inlet port at 100 psig.

3.4.6 Lubricants. - There shall be no lubricants used.

3.4.7 Propellant Drains. - The components shall be designed to minimize fluid entrapment for any installed attitude. The component shall ensure fluid removal by dry gas purging.

3.5 Environmental and Load Factors. - The Propellant System and Thrust Chamber Assemblies shall be required to meet all the requirements of this specification during and after exposure to the combined environment specified in Table II.

3.5.1 Radiation Environment. - Charged particle and electromagnetic radiation originating from the sun and other celestial sources, shall be considered in the design of the PS/TCA. The vendor shall notify Grumman of any items which may be adversely affected. A detailed description of this environment will be provided where it is necessary to evaluate overall reliability.

3.6 Fabrication. -

3.6.1 Materials and Processes. - In the selection of materials and processes, fulfillment of major design requirements shall be the prime consideration. Materials and processes selected shall be subject to Grumman approval.

(a) In addition, processing equipment and certification of processing personnel shall be subject to Grumman approval.

(b) When temporary substitutions are made, drawings shall note the applicable government specification of the alternate material when applying for Grumman approval.

3.6.1.1 Dissimilar Metals. - Dissimilar metals shall not be used in intimate contact unless suitably protected against electrolytic corrosion. When it is necessary to assemble any combination of dissimilar metals, an approved interposing material compatible to each as well as the environment shall be used. Some of the more commonly used dissimilar metals are defined in the following groups.

GROUPING OF METALS

Group I — Magnesium and its alloys
Aluminum alloys 5052, 5056, 5356, 6061 and 6063.

Group II — Aluminum and its alloys including aluminum alloys listed in Group I.

Group III — Iron, Lead and Tin and their alloys (except stainless steel)

Group IV — Copper, chronium, nickel, (inconel), silver, gold, platinum, titanium, cobalt and rhodium and their alloys; stainless steels and graphite.

(a) Contact between a member of any one group and another member of the same group shall be considered as similar. Contact between a member of one group and a member of any other group shall be considered as dissimilar.

Group IV (Continued)

(b) Unless specifically approved by the procuring agency, all other metals shall be considered dissimilar with respect to each other and with respect to any of the materials listed above.

(c) The above grouping is intended to serve as a guide in selecting materials, and shall not be construed to waive other requirements of this specification pertaining to corrosion resistance of components and assemblies.

(d) Where reference is made to a metal in a particular group, the reference applies to the metal on the surface of the part; i.e., gold means gold wire, as well as gold electroplate.

(e) Different metals in contact, even though similar, shall be employed in assemblies in such manner that the smaller part is cathodic or protected and the larger part is anodic.

(f) Qualified standard parts and attaching hardware, which are cadmium, silver or nickel plated, etc., may be used without additional protection provided the finish thereon, is acceptable to Grumman and adequate protection against corrosion is afforded.

3.6.1.1.1 Protection Against Electrolytic Corrosion. - Where it is necessary that any combination of dissimilar metals be assembled, the following methods or combinations of methods shall be employed for the alleviation of electrolytic corrosion, unless other design considerations preclude the employment of such methods.

3.6.1.1.1 (Continued)

(a) Interposition of a material compatible to each to decrease electrolytic potential differences, such as nickel or silver plate on steel in contact with inconel.

(b) Interposition of an inert material between the dissimilar metals to act as a mechanical and insulating barrier.

(c) Design of dissimilar metal or similar metal contacts, in order that the area of the cathodic metal is relatively smaller than the area of the anodic metal, such as screws, of stainless steel or nickel plated brass in the contact with aluminum.

3.6.2 Processes. - All processes, processing equipment and certification or processing personnel shall be subject to Grumman approval.

3.6.2.1 Quality. - When non-governmental specifications are used for processes which may affect performance, reliability or durability of the PS/TCA such specifications shall be approved by Grumman. The use of non-governmental specifications shall not constitute waiver of inspection.

3.6.2.2 Workmanship. - The workmanship and finish shall be of sufficiently high grade to insure satisfactory operation, reliability and durability consistent with the service life and application of the PS/TCA.

3.6.2.3 Techniques. - Fuel and oxidizer passages in the thrust chamber assembly shall be separated by parent metal. The injector shall be designed and the fabrication processes shall be planned to prevent chips from remaining in the injector passages. Drilling into hidden passages shall be minimized or eliminated completely to allow deburring

3.6.2.3 (Continued)

of injector orifices. The propellant passages shall be designed to eliminate interpassage mixing of the fuel and oxidizer because of seal failures or weld deterioration.

3.6.3 Standards. -

3.6.3.1 Parts. - AN, MS, JAN, or MIL standard parts shall be used wherever they are suitable for the purpose, and shall be identified by their standard part numbers. The use of non-standard parts will be approved by Grumman only when standard parts have been determined to be unsuitable.

3.6.3.2 Design. - MS and AND design standards shall be used wherever applicable.

3.6.3.3 Joints. - Particular attention shall be paid to the development of high reliability, leak proof methods of joining the fluid system lines to the PS/TCA components. Installation configuration restraints affecting the method of joining will be defined by Grumman. Final configuration of the line attachment provisions on each of the PS/TCA components is subject to specified Grumman approval.

3.6.4 Special Tools. - No special tools shall be necessary for maintenance and servicing of the PS/TCA.

3.7 Identification of Product. -

3.7.1 Assemblies. - Permanent serialization of all major components shall be accomplished during manufacture. Identification of components shall be accomplished with nameplates or other suitable means. In cases where nameplates are employed, the following information shall be represented in accordance with MIL-STD-130:

3.7.1 (Continued)

Item Name

Prime Contractor Specification No.

Stock No.

Contract No.

Inspection Serial No.

Manufacturer's Part No.

Manufacturer's Name

Manufacturer's Serial No.

Assembly Date

U. S.

3.7.2 Components. - Components shall be clearly marked as follows:

Serial No.

Stock No.

Manufacturer's Part No.

Manufacturer's Name

3.7.3 Connections. - The rocket engine shall be permanently marked to indicate all connections shown on the installation drawing for instrumentation, propellant and electrical connections.

3.8 Reliability Requirements. -

3.8.1 Numerical Reliability. - The reliability goal shall be .9999 for completion of the mission requirements as detailed in this specification without a single failure. This goal shall include all operating and non-operating phases of launch and boost, space flight and lunar excursion.

3.8.2 Safety. - The probability of safety goal shall be .999999 for completion of the mission without catastrophic failures such as engine explosion or propellant leakage causing damage to other subsystems.

3.8.3 Operational Profile. - The reliability requirements of 3.8.1 and 3.8.2 shall be based on the operational time profiled in Table III.

4. QUALITY ASSURANCE PROVISIONS

4.1 General. - This section of the specification establishes general test requirements and procedures to be followed during the Propellant System and Thrust Chamber Assemblies (PS/TCA) test program. The vendor may propose additional tests to further increase the effectiveness of this program. Changes to specific tests and test conditions will evolve and be approved by Grumman based upon future vendor and Grumman study and development efforts. The test program shall consist of the following test categories:

(a) Development Tests

(b) Component Qualification Tests

(c) System Design Verification Tests

(d) Acceptance Tests

Reliability Assurance Test data shall be derived from results of tests listed above.

4.1.1 Witnessing of Tests. - Grumman shall be advised when tests are to be conducted so that a representative may be designated to witness the tests. Waiver of this requirement or delegation of alternate authority shall be at Grumman's discretion.

4.1.2 Criteria for Rejection. - Criteria for rejection of a test specimen shall be stated in the test plan. In general, any degredation in performance beyond specified limits shall be cause for rejection.

4.2 Test Facilities. -

4.2.1 General. - Private or commercial test facilities may be used subject to Grumman approval.

4.2.2 Environmental Test Facilities. - The environmental test facility or chamber shall be of a sufficient size and volume such that the item under test shall not interfere with the generation and maintenance of the required test condition.

4.2.3 Standard Conditions. - Tests conducted without utilizing special environments shall be conducted under the following conditions:

(a) Temperature in the range from +10°F to +110°F

(b) Relative Humidity: Local atmospheric

(c) Barometric Pressure: Local atmospheric

4.2.4 Instrumentation Calibration. - All inspection, measuring and test equipment shall be calibrated at intervals no greater than 30 days, against certified standards which have known, valid relationships to national standards. Apparatus used to measure test parameters shall not be in error greater than 10% of the tolerance of the specified parameters. Records shall be maintained indicating the date of last calibration and due date. Procedures shall be provided for periodic operational checks to be performed prior to the use of test and measuring apparatus. Calibrations shall be subject to approval by Grumman.

4.2.4.1 Tolerances. - The tolerance on environmental test conditions shall be established by the vendor for each test such that the nominal level insures meeting the minimum required test conditions except as noted in 4.2.4.1.1.

4.2.4.1.1 Specific Tolerances. - The tolerances on test conditions shall be as follows:

(a) Vibration Amplitude ± 10%

(b) Vibration Frequency ± 2%

(c) Shock Amplitude ± 15%

(d) Accel. Amplitude ± 10%

(e) Random Vibration - The vibration acceleration density applied to the test item shall be within ± 2 db of

4.2.4.1.1 (Continued)

(e) (Continued)

the specified test level over broad regions of the spectrum between 20 and 1000 cps and ±4 db between 1000 and 2000 cps.

4.2.5 Sensing and Recording. - Sensing and recording equipment of adequate response shall be used to obtain data during transient conditions of system and component operation requiring the evaluation of time versus variables.

4.2.6 Mounting Adapters. - The mounting adapters shall expose the items under test to the test environment in a manner that is representative of that in which it will be exposed in the LEM System.

4.2.6.1 Special Provisions. - Measured transient and oscillatory thrust forces transmitted to the cluster mounting locations, during firing, are required. These measurements shall be made on a rigid test stand acceptable to Grumman. The dynamic characteristics of both the cluster and the cluster test stand shall be measured in sufficient detail so that the adequacy of the measurements may be determined and corrections made if required. The cluster shall incorporate sensors for measuring vibrations about three axes in two chamber locations. One or more fittings shall be provided on the cluster to accommodate these sensors.

4.3 Test Procedures. - Shock, vibration and acceleration.

4.3.1 Shock. - An apparatus shall be used which is capable of providing a sawtooth shock load with a linear rise time of 11 ± 1 milliseconds and with a 1 ± 1 millisecond delay time. The test units shall be mounted in a manner identical to its normal mounting configuration. The measurement of the shock input shall be accomplished at the mounting interface of the test unit. The test shall be conducted under standard conditions.

4.3.2 Vibration. - The test units shall be attached to a mounting adapter in a manner identical with the actual mounting of the test unit in the spacecraft. The vibration shall be accomplished in the three mutually perpendicular directions parallel to the spacecraft x-x, y-y and z-z coordinate axes, defined in Figure 3. Test units and jig assemblies shall be mounted directly to the shaker head. If this type of mounting is not practicable, slip tables may be utilized. A complete log of each vibration test shall be maintained, including all resonant frequencies, instrumentation used, design changes made, and a detailed account of the performance of the equipment under test. In attempting to equalize the vibration input or in the determination of specimen or fixture resonances, it may be necessary to apply some vibration energy to the test unit prior to the actual test. In such cases the rms-g value shall be kept to a minimum and in any event shall not exceed 50% of that required during the actual test. All vibration tests will be conducted under both high and low temperature while undergoing the vibration requirements.

4.3.2.1 Vibration Fixtures. - The fixtures holding the test specimen on the shaker head shall be capable of transmitting the vibrations specified herein. It shall be a design objective that these fixtures are free of resonances within the test frequencies. In any event, resonant frequencies of fixtures compensated for test specimen mass shall be above 750 cps. The transverse motion (crosstalk) in any direction produced by these fixtures shall not exceed the vibration levels specified herein. The requirements outlined above shall be verified by a sinusoidal vibration test sweep using a dummy specimen of proper mass. The vibration input shall be monitored with tri-axial accelerometers.

4.3.2.2 Sinusoidal Vibration. - The vibration input levels shall be measured at or near each test unit mounting location. Wherever more than four mounting locations exist, only four points need be monitored. Any accelerometer fastened at one of the mounting locations can be used as the servo control input provided that:

4.3.2.2 (Continued)

(a) The control input maintains levels at the test frequency within ±1 db of the requirements.

(b) The level at any input location is within ±4 db of the requirements at all frequencies.

(c) The average of all inputs at each test frequency is within ±2 db of the requirements.

Exceeding the lower limits of the above tolerances will be cause for rejection of the delinquent portion of the test and will necessitate rerunning of that part of the vibration test. The recording of the accelerometer output signals shall be accomplished on a continuous recording device, e.g., magnetic tape, oscillograph, etc. The recorder shall have sufficient response capability such that the complete wave form of the signal may be examined and analyzed.

4.3.2.3 Random Vibration. - The vibration input shall be controlled from the same accelerometer as used to control sinusoidal vibration tests. The spectrum at test levels shall be analyzed and a plot of acceleration spectral density (g^2/cps) versus frequency shall be compiled for each random test. The analyzing filter shall have a maximum bandwidth of 1/3 octave or 100 cps, whichever is less.

4.3.2.4 Combined Sinusoidal and Random Vibration. - A sinusoidal sweep at 50% of the required sinusoidal levels shall be conducted first in accordance with 4.3.2.2. Then the vibration level for random input shall be equalized in accordance with 4.3.2.3. The actual test shall now be conducted by superimposing full level sinusoidal onto full level random excitations. The overall test level shall be recorded.

4.3.2.5 Resonance Search. - A sinusoidal resonance search shall be conducted at half or less of the required sinusoidal qualification test levels before any portion of the vibration test is conducted. Resonant frequencies and vibration amplifications shall be noted in the test log. The vibration amplification of any portion of the equipment shall be in accordance with 3.3.1.1.1.

4.3.3 Sustained Acceleration. - The test unit shall be mounted on the test apparatus (centrifuge) in such positions as to produce the required accelerations. The test apparatus shall be of such size that the gradient across the test item shall not be greater than ± 15 percent of the input acceleration through the c.g. of the test item. The test shall be run at standard conditions.

4.4 Classification of Tests. -

4.4.1 Development Tests. - Development tests are those tests conducted for the purpose of providing data for use in the design or to support the design of a specific component, section or subsystem. Development tests may be used to determine operating characteristics under off-design conditions. Test-to-failure type development tests can provide failure mode and weak link characteristics for verification of analyses and determination of strength margins. The vendor shall prepare a development test summary for approval by Grumman. Grumman reserves the right to require additional development tests as deemed necessary. Development tests shall include:

(a) Component Development Tests

(b) System Development Tests

4.4.1.1 Component Development Tests. - Component development tests shall include all tests conducted for the purpose of component and subassembly design and material selection, the investigation of component and subassembly performance

4.4.1.1 (Continued)

characteristics. During system development testing, procedures for cleaning and flushing the system and techniques for propellant loading shall be evaluated. There shall be a minimum of two development system configurations.

(a) Configuration number one shall consist of a standard vendor supplied pressurization system utilizing either nitrogen or helium as the gas pressurant and vendor supplied development hardware for the propellant feed system and thrust chamber assemblies.

(b) Configuration number two shall consist of advanced stage vendor development components for the purpose of conducting system integration tests with the GAEC supplied Helium Pressurization System (HPS).

4.4.2 Component Qualification Tests. -

4.4.2.1 General. - Qualification tests are tests which are conducted on samples identical to production PS/TCA components. All PS/TCA components requiring qualification, inspection, and testing as specified herein may have these requirements waived at the option of Grumman if the component has been previously qualified at the same or higher level for service use on another vehicle. These components must be substantially identical to the respective components previously qualified. If such a waiver is granted, detailed information on the components for which previous approval was obtained shall be provided. Qualification Tests on components shall be completed prior to the start of system design verification tests. The vendor shall prepare a separate Qualification Detail Test plan for each component and submit it to Grumman for approval prior to the start of Qualification Tests. Qualification Tests will be conducted on the following PS/TCA components:

(a) Fuel fill and vent disconnect couplings

4.4.2.1 (Continued)

(b) Oxidizer fill and vent disconnect couplings

(c) Fuel Tank

(d) Oxidizer Tank

(e) Burst disc

(f) Filter

(g) Main fuel shut-off valve

(h) Main oxidizer shut-off valve

(i) Fuel T.C.A. isolation valve

(j) Oxidizer T.C.A. isolation valve

(k) Thrust chamber assembly

(l) Instrumentation Transducers

Fuel and oxidizer components, that are identical with the exception of special compatibility provisions, may receive a combined qualification test subject to Grumman approval. All references to PS/TCA components for Qualification Tests from hereon includes all parts listed in items (a) through (l).

4.4.2.1.1 Component Inspection Before Tests. - All PS/TCA components shall be completely inspected for compliance with the approved drawings and specifications before qualification testing is begun. Deviations from the drawings and specifications shall be approved by Grumman. Defective parts shall not be used on any PS/TCA component subjected to qualification tests.

4.4.2.1.2 Component Inspection After Tests. - Upon completion of the Qualification Test the component shall be subjected to a detailed inspection of all vital working parts, the extent of disassembly shall be determined by Grumman inspectors. If any part is found to be defective an approved part shall be supplied to replace it and a suitable penalty test shall be conducted at the discretion of Grumman inspectors.

4.4.2.2 Tests. - The procedure for each environmental exposure for all tests shall be as follows:

(a) Pre-exposure examination and operational test as required.

(b) Exposure to environment and operational test as required.

(c) Post-exposure examination and operational test as required.

4.4.2.2.1 Environment. - PS/TCA components shall be subjected to the below listed test conditions of Table VI. Operational tests shall be derived from the duty cycle of Table III, where a combined environment creates a critical condition, e.g. TCA firing at altitude and temperature extremes, the qualification tests shall include testing under the combined environment if the combined environment occurs during one of the mission phases as outlined in Table II.

(a) Vibration, using the procedure of 4.3.2.

(b) Shock, using the procedure of 4.3.1.

(c) Acceleration

(d) High Temperature

(e) Low Temperature

4.4.2.2.1 (Continued)

(f) Sand and Dust

(g) Salt Fog

(h) Fungus

(i) Explosion

(j) Humidity

(k) Electrical Interference

4.4.2.2.1.1 Vacuum. - All components shall be subjected to a thermal vacuum test with the operating fluid or an approved test fluid contained in the component. The components shall be functionally tested in a vacuum of 7.5×10^{-10} mm Hg. The thrust chamber assembly does not have to be fired, however, the injector inlet valves shall be tested for functional operation. The tests shall be conducted at the high and low temperature of Table VI plus at a nominal temperature within the range of paragraph 4.2.3. TCA firing tests shall be conducted at a maximum pressure of 0.15 psia.

4.4.2.2.2 Fluid Compatability. - The effects on components of the chemical action of the propellants within the specification temperature limits of the propellants as well as the effects of aging with propellants drying in air, contact with vapors, or the worst combination thereof, shall be determined, and acceptance criteria shall be proposed in the test plan. The test conditions shall simulate as closely as practicable those encountered in the actual application. This test shall include aging of each component with the fluid with which it is to be used, for a period of approximately (30) days, and the last seven days under pressure which the component will be subjected to a normal mission operation.

4.4.2.2.3 Endurance. - Each component shall be subjected to an endurance test. The number of cycles shall be specified by the vendor in the qualification test plan.

4.4.2.2.4 Static Leakage. - All components shall be tested for static leakage starting at zero differential pressure and increasing at a rate consistent with normal use to the MEOP.

4.4.2.2.5 Proof Pressure. - All components shall be tested at the proof pressure specified in Section 3.

4.4.2.2.6 Ultimate Pressure. - All components shall be tested at the ultimate pressure specified in Section 3.

4.4.2.2.7 Electrical Tests. - All electrical components shall be tested according to MIL-STD-202, Methods 301 and 302.

4.4.2.2.8 Functional. - A functional test shall consist of the specified number of cycles of operation of the component. Sufficient measurements shall be made over the entire test period to compare the most significant dynamic and static control functions for each environmental condition under which the test is conducted. Performance throughout the various functional tests shall be within the limits specified.

4.4.2.2.9 Calibration. - Sufficient dynamic and static measurement data shall be obtained to empirically define the functions of the components within the normal operating range including discontinuties, hysteresis, and dead bands. The recalibration values determined during testing shall remain within the performance limits specified.

4.4.2.2.10 Malfunction. - A malfunction test shall be performed on all components based on the malfunction analysis of 3.2.1.5.

4.4.2.2.11 Weight. - All PS/TCA components shall be weighed dry.

4.4.3 Design Verification Tests. -

4.4.3.1 General. - Design verification tests are advanced stage development tests which are performed to demonstrate the proper performance and operating characteristics of the prototype design. Design verification hot firing tests will be conducted on complete PS/TCS's at sea level, and on thrust chamber assembly clusters under simulated altitude conditions.

4.4.3.1.1 Selection of Test Limits. - Unless otherwise specified for a particular test, the test limits for the design verification tests shall be as shown in Table VI.

4.4.3.1.2 Parts Failure and Replacement. - Maintenance, adjustment, or replacement of parts shall not be permitted, during design verification testing except when approved by Grumman. The replacement part shall be a redesigned part or one of different material unless Grumman authorizes the installation of a new part of original design.

4.4.3.1.3 Inspection After Tests. - After completion of tests, calibrations shall be made of all controls and control components prior to disassembly. These calibrations shall demonstrate that the components are within the design tolerance range required. The test articles shall then be completely disassembled. Visual examination and measurements of all parts shall be made. Where practicable, photographs shall be taken of all excessively worn, distorted or weakened parts.

4.4.3.1.4 Design Verification Conditions. - Verification of the PS/TCA and cluster designs shall be predicated on maintenance of all parameters within the limits specified.

4.4.3.2 PS/TCA Design Verification. -

4.4.3.2.1 General. - System design verification tests are conducted on a complete PS/TCS with fully loaded and temperature conditioned propellant tanks and with a Grumman supplied helium pressurization system. The system shall be installed on a test stand fabricated to comply with Grumman definitions of LEM location points. Each component shall be of qualified design, but within this constraint, previously used development and qualification test hardware may be employed where practical.

4.4.3.2.2 Data Requirements. - The test system shall be instrumented to provide a continuous record of the following values:

(a) Propellant feed pressures to each thrust chamber assembly.
(b) Chamber pressure.
(c) Oxidizer and fuel tank pressures.
(d) Primary pressure-regulator discharge pressure.
(e) Gas pressurization source pressure and temperature.
(f) Oxidizer and fuel flow rates for each thrust chamber.
(g) Current/voltage for each thrust chamber valve.
(h) Thrust chamber injection and propellant temperatures.
(i) Barometric pressure.
(j) Other, as required to demonstrate performance.

NOTE: Thrust values will be measured indirectly with the thrust coefficient characteristics determined from individual thrust chamber assembly tests.

Using the above measured values, the vendor shall derive the thrust coefficient characteritics determined from individual thrust chamber assembly tests.

4.4.3.2.2.1 Pulse Mode. - The following characteristics shall be derived for the first five pulses, the middle pulse and the final pulse of each thrust chamber assembly firing series.

(a) Total impulse per pulse.
(b) Average specific impulse per pulse.
(c) Average mixture ratio per pulse.
(d) Average chamber pressure per pulse.
(e) Average thrust per pulse.
(f) Total impulse "time centroid" of each pulse.
(h) Other, as required to demonstrate performance.

The following characteristics shall be derived from a compilation of the first, middle, and final pulses of all applicable thrust chamber assembly test series employed in PS/TCA verification testing.

(a) Average specific impulse per pulse vs. pulse width.
(b) Total impulse per pulse vs. pulse width and off-time.
(c) Average chamber pressure per pulse vs. pulse width.
(d) Average thrust per pulse vs. pulse width.
(e) Thrust pulse width vs. electrical pulse width and hardware temperature.
(f) Average mixture ratio per pulse vs. pulse width.
(g) Average characteristic velocity per pulse vs. pulse width.
(h) Maximum soak-back temperature vs. pulse width and off-time.
(i) Other, as required to demonstrate performance.

4.4.3.2.2.2 Steady State Mode. - The following operational characteristics based on the first point, mid point, and final point of each thrust chamber steady state run shall be derived:

(a) Total impulse of run.
(b) Mixture ratio.
(c) Specific impulse.
(d) Thrust.
(e) Other, as required to demonstrate performance.

4.4.3.2.2.2 (Continued)

The following operational characteristics shall be derived from a compilation of all applicable mid-points of each thrust chamber steady state run employed in PS/TCA verification testing.

(a) Deviation from design nominal of mixture ratio vs propellant temperatures.
(b) Deviation from design nominal of specific impulse vs oxidizer and fuel temperatures.
(c) Deviation from design nominal of chamber pressure and thrust vs oxidizer and fuel temperature.
(d) Other, as required to demonstrate operational characteristics.

4.4.3.2.3 PS/TCA Tests. - The PS/TCS shall be subjected to the below listed tests which are detailed in the succeeding paragraphs of this specification. The number of systems employed and order of tests shall be specified in the detailed test plan. The detailed test plan shall define the use of the power and emergency coils of the thrust chamber solenoid valves to demonstrate operational and life characteristics of each coil.

(a) Static Leakage - The PS/TCA shall be tested for static leakage starting at zero differential pressure and increasing at a rate consistent with normal use to the MEOP.

(b) Vibration - The PS/TCA shall be subjected to the vibration inputs specified in Table VI, using the procedure of 4.3.2.

(c) Shock - The PS/TCA shall be subjected to the shock loads specified in Table VI. The PS/TCA shall be mounted and the shock loads shall be applied in accordance with 4.3.1.

(d) Fixed Thrust - Two runs of test series number 10 of Table V shall be conducted at ambient temperature.

4.4.3.2.3 (Continued)

(e) Attitude - Test series number 9 of Table V shall be conducted at ambient temperature for each of the following attitudes:

(1) + 45° about y axis
(2) - 45° about y axis
(3) + 45° about z axis
(4) - 45° about z axis
(5) + 45° about y and z axis
(6) + 45° about y axis, - 45° about z axis
(7) - 45° about y and z axis
(8) - 45° about y axis, + 45° about z axis

(f) High Temperature - The thrust chamber clusters shall be conditioned to the maximum temperature resulting from calculations employing Grumman supplied vehicle emissivities, view factors and time durations in the temperature-view environments specified in Table IId. Propellants shall be conditioned to within -0°F, to +5°F of the values specified in Table II under tanks and components. The PS/TCA shall then be run in accordance with test series number 12 of Table V. The thrust chamber propellant valves shall then be allowed to reach maximum temperature after shutdown, at which time the PS/TCA shall be run in accordance with test series number 13 of Table V.

(g) Low Temperature - The thrust chamber clusters shall be conditioned to the minimum temperature resulting from calculations employing Grumman supplied vehicle emissivities, view factors, and time durations in the temperature-view environments specified in Table IId. Propellants shall be conditioned to within -5°F to +0°F of the values specified in Table IId under tanks and components. The PS/TCA shall then be run in accordance with test series number 10 of Table V.

4.4.3.2.3 (Continued)

(h) Electromagnetic Interference - The PS/TCA shall be subjected to electromagnetic interference tests as specified in the detailed test plan.

(i) Decontamination and Storage - With the PS/TCA in the normal launch attitude the liquid system shall be completely filled with propellants then drained, flushed, and decontaminated employing procedures developed for launch and field operations. The system shall then be removed for 30 days storage. Following storage, the system shall be run at ambient temperature in accordance with test series number 10 of Table V.

(j) Weight - Each PS/TCA shall be weighed dry.

(k) Variable Voltage - Part of the total cycles specified in test series 1 thru 6 of Table V shall be conducted at the extremes and intermediate levels of the voltage tolerances established for the thrust chamber for the thrust chamber solenoid valves.

(1) 10% of the total number of cycles shall be at maximum voltage.

(2) 10% of the total number of cycles shall be at minimum voltage.

(3) 10% of the total number of cycles shall be at intermediate voltages differing from nominal.

(l) Malfunction - The type and order of these tests, based on the malfunction analyses required by 3.2.1.5 shall be proposed in the test plan. Compliance with 3.2.1.5 shall be demonstrated after occurrence of all of the events proposed in the test plan during either transient or stabilized operation of the PS/TCA. A representative number of the malfunction combinations analyzed shall be investigated by test.

4.4.3.2.3 (Continued)

(m) Durability - Test series number 11 of Table V shall be performed to demonstrate PS/TCA performance for the required thrust chamber continuous run life requirement. Following this test series the same thrust chamber assemblies shall be fired in pulse mode operation as follows:

(1) Pulse at 25 cps for 400 seconds with an electrical pulse width of .025 seconds.

(2) Pulse at .25 cps with a pulse yielding the minimum impulse bit of Table I. The duration at .25 cps shall be sufficient to accumulate 500 seconds of pulse mode firing time with the inclusion of the time accumulated at 25 cps.

The remaining tests of Table V shall be performed to demonstrate satisfactory starts and shutdowns and to gain reliability data. The tests shall consist of: test series Number 7 and 8, and 350 cycles of test series 1 through 6. In addition, test series number 10 shall be run 7 times and test series Number 9 shall be run twice.

(n) Additional Tests - Additional tests, for the purpose of testing special features of the PS/TCA and propellants may be required by Grumman. In general, these tests will utilize the runs previously mentioned and will not increase the total running time accumulated during the verification test.

4.4.3.3 Cluster Design Verification. - Cluster design verification tests supplement the PS/TCA tests. Cluster tests verify the design considerations attendant to the thermal effects of clustering the high area ratio nozzles. Hot firing tests will be conducted at a sufficiently low ambient pressure to:

(a) Insure fully flowing nozzles.

4.4.3.3 (Continued)

(b) To achieve sufficient plume expansion and negligible convection cooling to verify proper operation during space flight.

4.4.3.3.1 General. - Cluster design verification tests are conducted on an assembly consisting of a cluster mount and four thrust chamber assemblies. Each component shall be of qualified design, but within this constraint, previously used development and qualification test hardware may be employed. The propellant feed system need not employ bladders or prototype components, but shall provide feed pressure and transient responses which are consistent with a prototype feed system. A section of LEM vehicle skin structure shall be mounted to simulate cluster placement on the vehicle.

4.4.3.3.2 Data Requirements. - Instrumentation shall be implemented to provide a continuous record of the following values:

(a) Propellant feed pressures

(b) Chamber pressures

(c) Oxidizer and fuel flow rate to each thrust chamber

(d) Current/voltage to each thrust chamber valve

(e) Thrust chamber assembly, valve and skin temperatures

(f) Ambient pressure

(g) LEM skin temperatures

(h) LEM skin heat fluxs

(i) Other as required to demonstrate performance

4.4.3.3.2 (Continued)

Using the above measured values, the vendor shall compile and derive all data pertinent to correcting PS/TCA operational characteristics for the effects of the added thermal environment induced by full nozzle flows.

4.4.3.3.3 Cluster Tests. - The vendor shall provide a detailed test plan to be approved by Grumman prior to the initiation of cluster design verification testing. Test plan shall include the amount hardware employed and the sequence of cluster tests. The tests shall include but not be limited to the following:

4.4.3.3.3.1 Correction Data. - The test plan shall include provisions for producing correction data for application to PS/TCA design verification tests. The purpose of the correction data is to compensate environment induced by fully flowing nozzles and exhaust plume.

4.4.3.3.3.2 Simulated Missions. - The mission phases of Table III shall be utilized to develop a test plan to test for the worst duty cycles imposed on a cluster during the mission. The test plan shall include but not be limited in the following operational conditions (within design tolerances) during simulated mission tests:

(a) High mixture ratio

(b) High chamber pressure

(c) High temperature propellants and cluster hardware

4.4.3.3.3.3 Endurance Tests. - The test plan shall include tests to demonstrate the life requirements specified in Table I. Endurance tests shall include combined operating characteristics of high mixture ratio, high chamber pressure, and high temperature view-environment.

4.4.3.3.3.4 Maximum Heat Soak-Back. - Included in the test plan shall be tests under the most adverse duty cycles to attain the highest thrust chamber valve temperatures prior to continuing steady state and pulse mode tests.

4.4.4 Acceptance Tests. - Acceptance tests are tests conducted on PS/TCA's and components to show that the equipment is representative of, and the performance is equivalent to, the equipment used in design verification and qualification tests. All PS/TCA's and qualification tests, and all PS/TCA's delivered under this purchase order shall be subjected to acceptance tests.

4.4.4.1 General.- The PS/TCA components, test apparatus and the material entering into the manufacture of articles for fulfillment of the LVR-310-2 shall be subject to inspection by authorized Grumman inspectors. At convenient times prior to the tests and after the tests, the PS/TCA and components shall be examined to determine compliance with all requirements of LVR-310-2 and specifications. During the progress of tests, examinations may be made at the option of Grumman. No item for use on flight spacecraft shall contain a component or element which has been subjected to more than three acceptance test programs, nor shall an item be used which has been subjected to environments of an intensity higher than acceptance test levels. Acceptance tested components shall not be disassembled.

4.4.4.2 Test Facilities and Procedures. - The acceptance test procedure for the PS/TCA and each component shall be supplied by the vendor for Grumman approval. All thrust chamber firings are to be conducted under simulated altitude conditions.

4.4.4.3 Inspections and Tests. -

4.4.4.3.1 PS/TCA Inspection Before Acceptance Tests. - Each PS/TCA shall be completely assembled in accordance with the Grumman approved drawings, then visually and dimensionally inspected before commencing tests.

4.4.4.3.2 PS/TCA and Component Tests. - Each PS/TCA and component assembled for the inspection specified above shall be subjected to the following tests:

(a) Weight - The dry PS/TCA and components shall be weighed and recorded.

(b) Static Leakage - Static leakage tests shall be made on each PS/TCA and component according to the acceptance test plans.

(c) Functional Tests - All PS/TCA and components shall undergo functional tests to insure proper operation.

(d) Calibration - The PS/TCA shall be operated for a duration and at thrust levels sufficient to demonstrate compliance with performance ratings specified. The attitude of the PS/TCA and the sequence of its operation shall be as specified in the test plan.

(e) PS/TCA Component Tests - All components of the PS/TCA shall be functionally checked under the operating conditions of Table VI and in accordance with the test plan.

(f) Proof Pressure - All PS/TCA components shall be tested at the proof pressure specified in Section 3.

4.4.4.3.2 (Continued)

(g) Firing Tests - One programmed run as specified in the approved test plan shall be made on the thrust chamber assembly.

(h) Additional Tests - Additional tests, for the purpose of testing special features of the PS/TCA and propellants, may be required by Grumman. These tests shall be outlined in the test plan and shall not, in general, increase the total running time accumulated during the acceptance tests.

4.4.4.3.3 Acceptance Conditions. - Acceptance of the PS/TCA and its components shall be predicated on maintenance of all parameters within the limits specified throughout all tests.

4.4.4.3.4 PS/TCA Inspection After Test. - Upon completion of the acceptance tests, the PS/TCA shall be subjected to a detailed inspection. If any part is found to be defective, an approved part shall be supplied to replace it, and a suitable penalty test shall be conducted at the discretion of Grumman inspectors.

4.4.4.3.5 Rejection and Retest. - Whenever, in the opinion of Grumman inspectors, there is evidence of insufficient thrust or other malfunctioning, or evidence that the PS/TCA or component is not meeting the specified requirements, the difficulty shall be investigated and its cause corrected to the satisfaction of Grumman inspectors before the test is continued. At the option of Grumman inspectors, that portion of the test in which the difficulty was encountered shall be repeated. The maximum retest shall consist of a repetition of the test runs outlined above.

4.4.4.3.6 Maximum Running Time. - A PS/TCA and components shall be rejected whenever the total running time accumulated during the tests specified herein exceeds the time allowed for in

4.4.4.3.6 (Continued)

the acceptance test plan. Components from rejected PS/TCA may be reused if such items can be reconditioned to meet the requirements for new parts. The Grumman inspector shall be furnished full particulars of previous PS/TCA and component rejection when such items are resubmitted for inspection.

4.4.5 RELIABILITY ASSURANCE

4.4.5.1 General. - As an integral part of the test development program listed in paragraph 4.1, the vendor shall demonstrate that the minimum reliability assurance requirements of 4.4.5.2 have been met or exceeded. Tests applicable to reliability assurance shall fulfill the following requirements:

(a) The test shall be conducted on flight weight (prototype) hardware.

(b) The test hardware shall be subjected to one mission simulation at the critical reliability boundary conditions of 4.4.5.2 with hardware operating or non-operating as applicable.

(c) The test hardware shall be stressed to failure under selected critical environments.

The reliability assurance demonstrated during the Development Tests shall be supported by the additional results obtained from the Component Qualification Tests and the Design Verification Tests.

4.4.5.2 Reliability Assurance Requirements. - Statistical analysis of the results of a stress-to-failure test (see Appendix I, Section E of LVR-310) shall show that the probability of occurrence of a failure at levels of severity less than

4.4.5.2 (Continued)

the critical environmental, dynamic, or operation conditions established by the Reliability Boundary is no more than 5%. This statement shall be made with a statistical confidence of 90%.

(a) Reliability Boundary - The Reliability Boundary may be established in two ways:

(1) From Available Empirical Data - Where reliable date is available which can be applied to the LEM Mission, the Reliability Boundary shall be established as that level of environmental, dynamic, or operational severity for which the probability of occurrence of a more severe environment in the actual mission is no more than 1%.

(2) By Sound Engineering Judgment - When no acceptable empirical data is available, the Reliability Boundary will be set at 1.15 times the maximum mission design conditions for dynamic loads. The Reliability Boundary for conditions of temperature, vacuum, and associated space environments shall be established on the basis of engineering judgment containing similar margins. The Reliability Boundary should be representative of the mission profile so that the predicted failure mode in the stress-to-failure portion of the test will be uncovered.

4.4.5.2.1 Reliability Assurance of PS/TCA Components. - As an integral part of the development test program, PS/TCA components such as valves, tanks, etc. (except the thrust chamber), shall demonstrate compliance with 4.4.5.1. Reliability Boundary conditions shall take into account the environments and dynamic conditions to which the PS/TCA will be exposed in the pre-launch, launch, translunar and lunar phase of the LEM mission. Stress-to-failure tests shall commence after subjecting the PS/TCA to one mission simulation at Reliability Boundary conditions. Operating time or number of cycles shall not be overlooked as a possible criterion variable.

4.4.5.2.1 (Continued)

(a) Reliability Hardware Utilization - Reliability Assurance Tests shall be run on flight weight hardware. The quantity of hardware required to estimate Reliability Assurance shall be proposed by the vendor. However, in preparing the hardware utilization program, the vendor shall consider that be careful planning, these requirements can be met in the normal fulfillment of the component development test programs. The following factors shall be considered in proposing the number and nature of tests:

(1) In the stress-to-failure test, seven occurrences of the same failure mode for each test component type or a total of ten failures of the component shall be sufficient for analysis.

(2) If the failure mode anticipated during these tests is not destructive, a minimum of two components shall be tested to satisfy 4.4.5.2.

4.4.5.2.2 Reliability Assurance of Thrust Chamber Assembly (TCA). - The Reliability Assurance of the TCA shall be demonstrated in accordance with paragraph 4.4.5.2 as an integral part of the TCS development program. The vendor shall provide a minimum of seven (flight weight) TCS firing tests at altitude which duplicate the most severe combination of operating conditions expected during the actual mission. These are not necessarily additional hardware requirements, but may, where practical, be extensions or modifications of development or qualification tests already planned for other purposes. These tests shall also take into account the environmental and dynamic conditions to which the TCA will be exposed in the pre-launch, launch and translunar phase of the LEM mission. A simulation of these conditions shall be imposed on each of the designated engines prior to its firing test.

4.4.5.2.2 (Continued)

As a minimum, the reliability assurance of the TCA as per paragraph 4.4.5.2, shall be assessed from the results of the above tests, with additional substantiation from the results of the applicable portions of the thrust chamber qualification test program.

4.4.5.2.3 Reliability Assurance of PS/TCA. - The reliability assurance of the PS/TCA shall be assessed from those portions of the PS/TCA development tests which are applicable to reliability assurance plus the successful completion of the design verification test.

4.4.5.2.4 Analysis of Results. - The Weibull analysis technique is the procedure recommended for application to the results of the stress-test-to-failure. (Reference: paragraph 7.1.9.3 of Appendix I of Section E of LVR-310-2.)

5. PREPARATION FOR DELIVERY

5.1 General. - The subcontractor shall develop methods of preservation, packaging and packing for the equipment which will provide adequate protection against corrosion, contamination, physical damage from shock and vibration and other shipping hazards encountered during handling and transport to the contractor's facility, and during subsequent indoor storage. Packaging shall be designed to facilitate handling, inspection and warehousing of the equipment.

5.2 Reliability. - The required high reliability of the equipment makes it mandatory that there be no degradation of reliability as a consequence of handling, transport and storage. In demonstration of this requirement, the supplier shall provide laboratory or field test data, service use data or suitable analytical data to verify the adequacy of the packaging materials and methods used.

5.3 Marking of Shipments. - Interior and exterior containers shall be durably and legibly marked such that the markings shall provide the following information:

Item Name

Contractor's Control No.

Stock No.

Contractor's Order No.

Manufacturer

Manufacturer's Serial No.

Date of Manufacture

6. NOTES

6.1 Definitions. -

6.1.1 Assembly, Thrust Chamber. - The thrust chamber assembly (TCA) is composed of the thrust chamber, nozzle, injector, propellant valves, mounting provisions, and any other directly associated parts.

6.1.2 Chamber, Combustion. - The combustion chamber is the enclosed volume between the injector face and the throat of the nozzle.

6.1.3 Conditions, Standard. - Standard conditions are the values of air temperature and pressure given in NACA Technical Report No. 218. The standard humidity, for the purpose of this specification, is zero vapor pressure at all altitudes.

6.1.4 Cutoff. - Cutoff is the time of propellant flow cessation through the thrust chamber propellant shutoff valve(s).

6.1.5 Duration. - The duration is the total firing time of one operational cycle (seconds).

6.1.6 Impulse, Effective. - Effective impulse is the area under the thrust-time curve between the two 90-percent-of- rated thrust points.

6.1.7 Impulse, Effective Specific. - The effective specific impulse is the effective impulse divided by the total weight of propellant(s) consumed.

6.1.8 Impulse, Instantaneous Specific. - The instantaneous specific impulse (I_s) is the thrust produced, in pounds, divided by the total propellant consumption rate in pounds per second.

6.1.9 Impulse, Mean Specific. - The mean specific impulse is the total impulse divided by the total weight of propellant(s) consumed.

6.1.10 Impulse (Minimum Bit). - The smallest possible repeatable total impulse bit.

6.1.11 Impulse, Total. - The area under the thrust-time curve.

6.1.12 Interchangeable Parts. - Those parts which can be directly substituted for one another (both physically and functionally) by use of standard tools without cutting, fitting, or adjusting are interchangeable.

6.1.13 Model Classification. -

(a) Breadboard Model - This is an assembly of preliminary components to provide the feasibility of the system, or principle in rough form without regard to the eventual overall design or form of parts.

(b) Development Model - This is a model designed to meet the performance requirements of the specification and to establish technical requirements for production equipment. This model employs approved parts or their interchangeable equivalents. It may be used to demonstrate the reproducibility of the equipment.

(c) Prototype Model (Preproduction) - This is a model suitable for complete evaluation of mechanical and electrical form, design, and performance. It is of final mechanical and electrical form, employs approved parts, and is completely representative of final equipment. An equivalent of prototype is prequalification or design frozen hardware. Prototype hardware need not have been manufactured with production tooling.

(d) Production Model - This is an equipment in its final mechanical and electrical form, employs approved parts, and is completely representative of final equipment. Schedule permitting, qualification tests should be run on production model equipment.

6.1.14 Operation, Continuous. - Duration greater than one second.

6.1.15 Operation, Pulse Mode. - Duration less than one second.

6.1.16 Points, 90 Percent of Rated Thrust. - The 90 percent-of-rated thrust points are the time points during thrust increase and decrease between which the thrust is stabilized at greater than 90 percent of rated value.

6.1.17 Pressure, Chamber Design. - The maximum expected pressure in the chamber during operation.

6.1.18 Pressure, Effective Chamber. - The effective chamber pressure is the area under the chamber pressure-time curve between the two 90 percent-of-rated thrust points divided by the time interval between these points.

6.1.19 Pressure, Mean Chamber. - The mean chamber pressure is the area under the chamber pressure-time curve divided by the duration.

6.1.20 Pressure, Maximum Expected Operating. - The maximum expected operating pressure is the highest pressure that will appear in the PS/TCA. This value is determined from test observations.

6.1.21 Pressure, Proof. - At proof pressure there shall be no permanent deformation of the item or total deformation adversely affecting PS/TCA operation, or permanent set.

6.1.22 Pressure, Ultimate. - At ultimate pressure, there shall be no structural failure of the item.

6.1.23 Propellant, Referee. - A propellant incorporating the most adverse constituents of the specification propellant or which specifies propellant constituents after a 2-year storage period.

6.1.24 Ratio, Mean Mixture. - The mean mixture ratio (W_o/W_f) is the total weight of oxidizer consumed divided by the total weight of fuel consumed.

6.1.25 Replaceable Parts. - Replaceable parts are those parts that meet all the requirements of interchangeable parts except that cutting or unbrazing of fittings for removal is allowed.

6.1.26 Thrust. - Thrust (F) is the reactive force of the rocket engine during operation.

6.1.27 Thrust, Effective. - The effective thrust is the effective impulse divided by the time interval between the two 90 percent-of-rated thrust points.

6.1.28 Thrust, Mean. - The mean thrust is the total impulse divided by the duration.

6.2 Symbols. - Symbols used in this specification are defined as follows:

Symbol	Quantity	Unit
A_e	Exit Area	in^2
A_t	Throat Area	in^2
A_w	Chamber inner surface area	in^2
C_F	Thrust coefficient $\frac{F}{p_c A_t}$	Nondimensional
cps	Cycles per second	
c*	Characteristic velocity	ft/sec
D.A.	Double amplitude of vibration	
F	Thrust	lb
g	Earth gravity	32.2 ft/sec^2
in	Inches	
I_s	Instantaneous specific impulse	lb/lb/sec
I_t	Total impulse	lb sec
L*	Characteristic length	in
min	Minutes	
n	Load factor	Nondimensional
p	Absolute pressure	lb/in^2
p_c	Chamber pressure, absolute	lb/in^2
r_m	Instantaneous mixture ratio, W_o/W_f	Nondimensional

6.2 (Continued)

Symbol	Quantity	Unit
T	Absolute temperature	Rankine
V_c	Combustion chamber volume	in^3
W	Weight of fluid	lbs
W_f	Weight of fuel	lb
W_o	Weight of oxidizer	lb
w	Fluid flow rate	lb/sec
w_f	Fuel flow rate	lb/sec
w_o	Oxidizer flow rate	lb/sec
η	Efficiency	percent

6.3 Subscripts. -

Symbol	Quantity
al	altitude
c	chamber
d	discharge
e	exhaust nozzle; exit
f	fuel
fr	friction
F	thrust
i	inlet

6.3 (Continued)

Symbol	Quantity
m	mixture
o	oxidizer
p	pressure
s, sp	specific
sl	standard sea level
st	static
vp	vapor pressure
w	wall; surface
z	height

TABLE I

GENERAL REQUIREMENTS AND PERFORMANCE RATINGS (VACUUM)

General Requirements

Number of thrust chambers required	16
Thrust chamber type	Radiation cooled
Thrust chamber arrangement	4 clusters of 4 each
Oxidizer	Nitrogen tetroxide
Fuel	50% hydrazine + 50% UDMH
System total propellant	500 lbs. (nominal)
Number of tanks and pressure	2 oxidizer at 181 ± 2 psia nominal 2 fuel at 181 ± 4 psia, nominal

Nominal Performance Ratings (Vacuum)

Thrust per chamber	100 lbs. ± 5%
* Thrust chamber pressure	* ± *%
Nozzle area ratio, Ae/At	40
Propellant Mixture ratio (by O/F weight)	
Minimum impulse	.5 lb. sec. ± .1 lb. sec.
Thrust chamber operating life	

(a) 500 seconds of continuous thrust duration plus

(b) 500 seconds of accumulated on time during pulse mode operating consisting of:

* To be determined by vendor

TABLE I (Cont.)

(b) (1) .025 sec. electrical pulse width at 25 cps for 400 seconds

(2) Minimum impulse at .25 cps for remainder of time. (60 SEC)

Start transient to 90% rated thrust (measured from initiation of a 28 volt step input)	See Figure 4
Decay transient to 5% rated thrust (measured from termination of voltage input)	See Figure 4
Specific impulse (continuous operation)	300 secs.
Specific impulse (pulsing mode operation)	See Figure 5

TABLE II

ENVIRONMENTAL AND LOAD CONDITIONS

The following conditions apply to tanks (T), components (C) and/or thrust chamber clusters ("quads") (Q).

NOTES: 1. Factors of safety are not included in these levels. See paragraph 3.3.1.1.

2. All accelerations are in "earth g's". Multiply by earth weight or use 32.2 ft/sec^2 as appropriate.

(a) Pre-Launch

Temperature	T, C, Q	-65° to +160°F
Acceleration	T, C, Q	2.67g vertical with 1.0g lateral
Shock	T, C, Q	
Packaged		Transporation, handling and storage in shipping container shall not produce critical design loads on the T, C, Q and shall not increase the weight of the T, C, Q.
Unpackaged		15g peak sawtooth shock pulse as specified in Table VI.
Vibration	T, C, Q	The following vibration levels are specified during transportation, handling, and storage. Vibration shall be applied along three mutually perpendicular axes applied to container (sweep at 1/2 octave/minute).

cps	Less than 50 lbs.	50 lb. to 1000 lbs.
5-27.5 cps	± 1.23 g	± 1.0 g
27.5-52 cps	.033DA	.0277DA
52-500 cps	± 4.61 g	± 3.84 g

TABLE II (Continued)

(a) Pre-Launch (Continued)

Rain	T, C, Q	In accordance with MIL-STD-810, Method 506.
Salt Fog	T, C, Q	In accordance with MIL-STD-810, Method 509.
Humidity	T, C, Q	95% Relative Humidity including condensation in a temperature range of 0° to 160°F.
Electromagnetic Interference	T, C, Q	Per LSP-14-2
Sand and Dust	T, C, Q	In accordance with MIL-STD-810, Method 510.
Fungus	T, C, Q	In accordance with MIL-STD-810, Method 508.
Ozone	T, C, Q	Exposure with 0.05 parts/million concentration
Explosion	T, C, Q	In accordance with MIL-STD-810, Method 511
Pressure	T, C, Q	0 to 50,000 ft. altitude atmospheric pressure corresponding to

(b) Launch and Boost

Temperature	Q	-65° to +160°F
	T, C	+40° to +100°F
Vibration	T, C, Q	Sinusoidal vibration shall be superimposed on the random vibration
Random Vibration	T, C, Q	Random vibration shall be 17 mins along each of the three mutually perpendicular axes with x, y and z.

TABLE II (Continued)

(b) Launch and Boost (Continued)

Random Vibration (Continued)

15 to 100 cps linear increase $.0063g^2$ cps to $.0355g^2$/cps
100 to 1000 cps - constant $.0355g^2$/cps
1000 to 2000 cps linear decrease $.0355g^2$/cps to $.0089g^2$/cps.

Sinusoidal Vibration — T, C, Q — A sinusoidal vibration shall be superimposed sweeping logarithmically from 5 to 2000 cps in 6 minutes for each of the mutually perpendicular axes x, y and z.

5 to 10 cps	.154 in. DA
10 to 18 cps	±.77g
18 to 56 cps	.046 in. DA
56 to 2000 cps	±7.7g

Acoustics — T, C, Q

Octave Band (cps)	a Level (db)	b Level (db)
9 to 18.8	142	-
18.8 to 37.5	141	-
37.5 to 75	141	143
75 to 150	138	149
150 to 300	134	155
300 to 600	130	155
600 to 1200	123	155
1200 to 2400	116	155
2400 to 4800	110	143
4800 to 9600	104	131
Overall	147	160

NOTE: Environment may be (a) or (b) but not both together.

TABLE II (Continued)

(b) Launch and Boost (Continued)

Radiation	T, C, Q	See paragraph 3.5.1.			
Electromagnetic Interference	T, C, Q	Same as pre-launch			
Humidity	T, C, Q	Same as pre-launch			
Sand and dust	T, C, Q	Same as pre-launch			
Altitude	T, C, Q	Sea level to 1×10^{-10} mm. Hg.			
Explosion	T, C, Q	Same as pre-launch			
			x	Lateral	Pitch
Acceleration	T, C, Q	Boost cond (a)	5.64	3.4	± 1.27 rad/sec^2
		Boost cond (b)	-1.40g	-	-
Meteoroids	Q	Same as Space Flight			

(c) Space Flight

Temperature*	T, C	40°F to 100°F	
	Q	Solar Flux	440 BTU/ft.^{2}hr.
	Q	Space	-460°F
Electromagnetic Interference	T, C, Q	Same as pre-launch	
Pressure Altitude	T, C, Q	1×10^{-14} mm Hg. uncontrolled vacuum	

* Temperature due to combined exposure of solar flux and space shall be determined by Vendor.

TABLE II (Continued)

(c) Space Flight (Continued)

Meteoroids	Q	Flux considerations shall be based upon Whipple's distribution of sporadic meteoroids in accordance with Table VII		
Radiation Source	T, C, Q	See paragraph 3.5.1.		
Ozone	T, C, Q	To be determined.		
Explosion		Same as pre-launch.		
		x	Lateral	Pitch
Acceleration (Condition)		-.450g	.110g	.373 rad/sec^2
Shock	T, C, Q			
(Condition a)		-.32g	.093g	.4 rad/sec^2
(Condition b)		-.84g	.12g	17.0 rad/sec^2
Vibration	T, C, Q	Sinusoidal vibration shall be superimposed on the random vibration.		
Random Vibration	T, C, Q	Random vibration shall be 6 mins. for each of three mutually perpendicular axes x, y and z. 5 to 100 cps linear increase .00415g^2/cps to .0237g^2/cps 100 to 200 cps constant .0237g^2/cps 200 to 2000 cps linear decrease .0237g^2/cps to .0089g^2/cps		
Sinusoidal Vibration	T, C, Q	A sinusoidal vibration shall be superimposed sweeping logarithmically from 5 to 2000 cps in 2 minutes for each of the three mutually perpendicular axes. 5 to 300 cps linear increase .0924g to 1.925g 300 to 1000 cps constant 1.925g 1000 to 2000 cps constant 1.54g		

TABLE II (Continued)

(d) Lunar Excursion (including ascent and descent)

Temperature*	Q	External solar flux 440 BTU/hr-ft^2
	Q	Lunar surface - -300°F to +250°F
	Q	Space - -460°F
	T, C,	Internal - +40°F to 100°F
Electromagnetic Interference	T, C, Q	same as pre-launch
Pressure Altitude	T, C, Q	1×10^{-12} mm Hg
Meteoroids	Q	Flux considerations shall be based upon Whipple's distribution of sporadic meteoroids in accordance with Table VII.
Radiation Source	T, C, Q	see paragraph 3.5.1

Accelerations T, C, Q	X	Lateral	Pitch
Condition Descent.....	1.10g	.16g	.667 rad/sec^2
Condition Ascent......	1.20g	.06g	2.00 rad/sec^2

Shock	T, C, Q	Approx. 8g peak, any axis for 10 to 20 ms (to be supplied at a later date)
Vibration		Sinusoidal vibration shall be superimposed on the random vibration
Random Vibration	T, C, Q	(due to engine) Random vibration shall be 11.5 mins. for each of the three mutually perpendicular axes x, y, & z 5 to 100 cps linear increase .0051g^2/cps to .0415g^2/cps

*The thrust chamber temperature caused by exposure to expected combinations of these environments including the effect of heating caused by the plume during descent, hover and ascent shall be determined.

TABLE II (Continued)

(d) (Continued)

		100 to 550 cps constant $.0415g^2$/cps
		550 to 2000 cps linear decrease $.0415g^2$/cps to $.0296g^2$/cps
Sinusoidal Vibration	T, C, Q	(due to engine) A sinusoidal vibration shall be super imposed sweeping logarithmically from 5 to 2000 cps in 4 minutes for each of the three mutually perpendicular axes x, y, & z
		5 to 400 cps linear increase .123 to 5.39g 400 to 2000 cps constant 5.39g

Vibration due to operation of the PS/TCA to be supplied by the vendor (T, C, Q).

Ozone	T, C, Q	To be determined.
Explosion	T, C, Q	Same as pre-launch
Sand and Dust	Q	To be supplied by Grumman

TABLE III
NOMINAL MISSION DUTY CYCLE

Mission Phase	Total Phase Time	Operation	Time of Operation	Duty Cycle*	Jets being used
Checkout	30 min.	Fire each jet	1.5 sec.	1	All
Separation & Pitch 90°	78 sec.	Trans in x direction	4.38 sec.	1	#13 & #5
		-90° min pitch	4.38 sec.	1	#2 & #10
			4 sec.	1	#1 & #6
			4 sec.	1	#9 & #14
		.1° dead zone limit cycle about x	78 sec.	1.6×10^{-4}	#7 & #15, #3 & #11
		y	70 sec.	1.6×10^{-4}	#9 & #14, #1 & #6
		z	78 sec.	1.6×10^{-4}	#1 & #14, #6 & #9
Descent Coast	29.5 min.	5° dead zone limit cycle about x, y and z	25 min	$.033 \times 10^{-4}$	#7,15,3,11,9, 14,1,6,1,14,6, 9
		.25° dead zone limit cycle about x, y and z	4.5 min	$.71 \times 10^{-4}$	#7,15,3,11,9, 14,1,6,1,14,6, 9
Coast one orbit	123 min	5° dead zone limit cycle about x, y and z	123 min	$.033 \times 10^{-4}$	#7,15,3,11,9 14,1,6,1,14,6, 9
Powered Descent & Roll 180°	5.5 min	.1° dead zone limit cycle about x, y and z	5.5 min	2.22×10^{-4}	#7,15,3,11,9 14,1,6,1,14,6, 9
		180° min. roll	4 sec	1	#7, 15
			4 sec	1	#3, 11

* Equivalent rated thrust (100 lb) time per thruster divided by time of operation.

TABLE III (Continued)

Mission Phase	Total Phase Time	Operation	Time of Operation	Duty Cycle*	Jets being used
Hover to Touch-down	2 min.	trans. along z	15 sec	1	#3, 15
			15 sec	1	#7, 11
		correct for 4000 in-lb	15 sec	.302	#1, 6
		unbalance about y	15 sec	.302	#9, 14
		.1° dead zone limit cycle			
		x	2 min.	3.12×10^{-4}	#7,15;#3,11
		y	1.5 min	3.33×10^{-4}	#9,14;#1, 6
		z	1.5 min	3.33×10^{-4}	#1,14;#6, 9
Roll 180° at lift off		Min 180° roll	3 sec	1	#7, 15
Powered Ascent & Pitch 90°	6 min		3 sec	1	#3, 11
		Compensate for 3500 in-lb unbalance about pitch & yaw	6 min	.265	#9,& 14 or #1 & 6 (Pitch) #1 & 14 or #6 & 9 (yaw)
		Min 90° pitch	2 sec	1	#9, 14
			2 sec	1	#1, 6
Ascent Coast	60 min	5° dead zone limit cycle			
		about x	50 min	$.20 \times 10^{-4}$	#7,15;#3,11
		y	50 min	$.234 \times 10^{-4}$	#9,14;#1, 6
		z	50 min	$.517 \times 10^{-4}$	#1,14;#6, 9
		.25° dead zone limit cycle			
		about x	10 min	4.0×10^{-4}	#7,15;#3,11
		y	10 min	4.64×10^{-4}	#9,14;#1, 6
		z	10 min	10.33×10^{-4}	#1,14;#6, 9
Rend and Docking	25 min	Trans in Z direction (ΔV= 630 ft/sec)	360 sec	1	#7, 11
		.1° dead zone limit cycle about x, y and z	25 min	10.8×10^{-4} about x & y 25.9×10^{-4} about z	#7,15,3,11,9, 14, 1, 6 #1,14;#6,9

TABLE IV

INSTRUMENTATION PICKUP REQUIREMENTS
(refer to figure 2 for location)

Location	Measurement Parameter	Expected Range	Operational or Research & Development	Group	Quantity
1	Fuel Quantity	0-100 lbm	O, R & D	IB	2
2	Fuel Tank Pres.	0-300 psia	O, R & D	II	2
3	Fuel Tank Temp.	0-120°F	R & D	II	2
4	Oxidizer Qty.	0-160 lbm	O, R & D	IB	2
5	Oxidizer Tank Pres.	0-300 psia	O, R & D	II	2
6	Oxidizer Tank Temp.	0-120°F		II	2
7	Fuel Line Pres.	0-300 psia	O, R & D	IB	2
8	Fuel Line Temp.	0-120°F		IB	2
9	Fuel Flow Rate	0-1.3 lbs/sec		V	2
10	Oxidizer Line Pres.	0-300 psia	O, R & D	IB	2
11	Oxidizer Line Temp.	0-120°F		IB	2
12	Oxidizer Flow Rate	0-2.1 lbs/sec		V	2
13	Fuel Pres.	0-300 psia	O, R & D	II	8
14	Fuel Temp.	-100 to 120°F		II	8
15	Oxidizer Pres.	0-300 psia	O, R & D	II	8
16	Oxidizer Temp.	-100 to 120°F	R & D	II	8
17	Chamber Pres.	0-125 psia	R & D	II	16
18	Chamber & Nozzle Skin Temp.	0-3000°F	R & D	II	32
19	Injector Housing Temp.	-100°F to +500°F	O, R & D	II	16

NOTE: Addition or removal of Research and Development instrumentation shall not compromise the operation of the system.

TABLE V

DESIGN VERIFICATION TESTS
(excluding malfunction tests)

Test Series No.		1	2	3	4	5	6	7	8	9	10	11	12	13
Pulse Width (secs)		.010	.020	.040	.080	.140	.200	.50	1.0	5.0	15.0	500	70	5
Frequency (cps)(*)		25	25	15	10	5	4	-	.25	-	-	-	-	-
No. of cycles/combination		500	500	500	500	500	500	20	10	10	10	1	1	1
Combination No.	Thruster Nos. Fired simultaneously (**)													
1	2,5	x	x	x	x	x	x	x		x	x			
2	9,14													
3	2,5,9,14													
4	1,6													
5	10,13													
6	1,6,10,13													
7	1,14													
8	5,10													
9	1,14,5,10													
10	2,13													
11	6,9													
12	2,13,6,9													
13	8,16								x			x	x	x
14	3,11													
15	8,16,3,11													
16	7,15												x	x
17	4,12													
18	7,15,4,12													
19	7,11													
20	3,15													
21	12,16													
22	4,8	x	x	x	x	x	x	x		x	x			

TABLE V (Continued

Test Series No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Pulse Width (secs)	.010	.020	.040	.080	.140	.200	.50	1.0	5.0	15.0	500	70	5
Frequency (cps)(*)	25	25	15	10	5	4	-	.25	-	-	-	-	-
No. of cycles/combination	500	500	500	500	500	500	20	10	10	10	1	1	1

Combination No.	Thruster Nos. Fired simultaneously (**)	1	2	3	4	5	6	7	8	9	10	11	12	13
23	2,10	x	x	x	x	x	x	x		x	x			
24	6,14													
25	2,10,6,14													
26	1,9													
27	5,13													
28	1,9,5,13	x	x	x	x	x	x	x		x	x			
29	1,5,9,13(**)													

(*) During the running of each item number, the constant frequency cited shall be interrupted a sufficient number of times to verify the effect of varying "down times" on pulse mode operation.

(**) During the running of items 1 thru 6, the unemployed thrusters of combination number 29 shall be run continuously during the first few pulses (approximately 5).

TABLE VI - REQUIREMENTS FOR QUALIFICATION TESTS

TEST DESCRIPTION	INTENSITY OR RATE	CYCLES OR TIME	REMARKS
(a) Prelaunch			Equipment non-operating and dry test conditions apply to tanks, components and thrust chamber clusters unless noted otherwise.
Temperature	$-65^{\circ}F$ $+160^{\circ}F$	Exposure for 12 Hrs. Exposure for 12 Hrs.	
Vibration - Items less Sinusoidal than 50 Lbs.	.5 in. D.A. 1.6g .043 in. D.A. 6.0g	5-8 cps. 8-27.5 cps. 27.5-52 cps. 52-500 cps.	Vibration shall be applied along three mutually perpendicular axes to the container. The frequency shall be swept at 1/2 octave per minute.
Items more than 50 lbs.	.5 in. D.A. 1.3g .036 in. D.A. 5.0g	5-7 cps. 7-27.5 cps. 27.5-52 cps. 52-500 cps.	
Humidity	95% Relative Humidity including condensation in a temperature range of 0° to $160^{\circ}F$.	Exposure for 5 days	
Sand and Dust Thrust chamber cluster	In accordance with MIL-STD-810, Method 510.		

TABLE VI - REQUIREMENTS FOR QUALIFICATION TESTS (Continued)

TEST DESCRIPTION	INTENSITY OR RATE	CYCLES OR TIME	REMARKS
(a) Prelaunch (Cont'd)			
Fungus (Electrical Components only)	In accordance with MIL-STD-810 Method 508		
Explosion	In accordance with MIL-STD-810, Method 511		
Electromagnetic Interference	In accordance with Grumman Specification LSP-14-2		
Shock (Unpackaged)	Sawtooth Pulse - 15g Peak	10 $\pm$ 1 Milliseconds rise time 1 $\pm$ 1 Milliseconds decay	Three shocks in each direction shall be applied along the three mutually perpendicular axes for a total of 18 shocks
Salt Fog	In accordance with MIL-STD-810, Method 509		

TABLE VI - REQUIREMENTS FOR QUALIFICATION TESTS

TEST DESCRIPTION	INTENSITY OR RATE	CYCLES OR TIME	REMARKS
(b) Launch and Boost			Equipment non-operating and dry except for propellant tanks & fill valves test conditions apply to tanks. Components and thrust chamber clusters unless noted otherwise.
Temperature Tanks & Components Thrust Chamber Cluster	+40°F to 100°F -65°F to 160°F		
Vibration Random	Linear increase from $.015g^2$/cps to $.06g^2$/cps.	50-100 cps.	Sinusoidal shall be superimposed on random vibration
	Constant $.06g^2$/cps.	100-1000 cps.	Random vibration shall be 30 minutes for each of the three mutually perpendicular axes for a total time of 90 minutes
	Linear decrease from $.06g^2$/cps to $.015g^2$/cps.	1000-2000 cps.	
Sinusoidal	Constant D.A. 0.20 in	5-10 cps.	Sinusoidal vibration shall be 5 minutes for each of the three mutually perpendicular axes for a total time of 15 minutes. The frequency shall be
	Constant 1.0g	10-18 cps.	
	Constant D.A. 0.06 in	18-56 cps.	
	Constant 10.0g	56-2000 cps.	

TABLE VI - REQUIREMENTS FOR QUALIFICATION TESTS (Continued)

TEST DESCRIPTION	INTENSITY OR RATE	CYCLES OR TIME	REMARKS
(b) Launch and Boost (Continued)			
Sinusoidal (Cont'd)			swept logarithmically from 5 to 2000 cps in 5 minutes.
Acceleration Condition A Condition B	X / Y and Z / Pitch: $+8.5g$ / $\pm 5.1g$ / 1.9 radians/sec^2 $-2.1g$	Exposure for 5 minutes per direction for a total of 15 minutes.	Accelerations of condition A shall be combined.

TABLE VI - REQUIREMENTS FOR QUALIFICATION TESTS

TEST DESCRIPTION	INTENSITY OR RATE	CYCLES OR TIME	REMARKS
(c) Space Flight			Equipment non-operating & dry except for propellant tanks & fill valves. Test conditions apply to tanks, components and thrust chamber clusters unless noted otherwise.
Temperature Tanks & Components Thrust Chamber Clusters	40° to 100°F Solar Flux 440Btu/ft^2 hr. Space -460°F.		Temperature due to combined exposure of solar flux and space shall be determined by vendor.
Vibration Random	Linear increase from .012g^2/cps to .040g^2/cps. Constant .040g^2/cps Linear decrease from .040g^2/cps to .015g^2/cps.	15-100 cps 100-200 cps 200-2000 cps	Sinusoidal vibration shall be superimposed on random vibration Random vibration shall be 15 minutes for each of three mutually perpendicular axes for a total time of 45 mins.

TABLE VI - REQUIREMENTS FOR QUALIFICATION TESTS (Continued)

TEST DESCRIPTION	INTENSITY OR RATE	CYCLES OR TIME	REMARKS
(c) Space Flight (Cont'd)			
Sinusoidal	Constant Velocity 1 in./sec. Constant 2.5g Constant 2.0g	5-150 cps 150-1000 cps 1000-2000 cps	Sinusoidal vibration shall be 5 minutes for each of the three mutually perpendicular axes for a total time of 15 minutes. The frequency shall be swept logarithmically from 5 to 2000 cps in 5 mins.

TABLE VI - REQUIREMENTS FOR QUALIFICATION TESTS (Continued)

Test Description	Intensity or Rate	Cycles or Time	Remarks
(d) Lunar Descent & Ascent			Equipment operating. Test conditions apply to tanks, components and thrust chamber clusters unless noted otherwise.
Temperature			
Tanks and Components Thrust Chamber Clusters	$+40^{o}F$ to $+100^{o}F$ Solar flux 440BTU/ft^2 hr. Space $-460^{o}F$		Temperature due to combined exposure of solar flux and space shall be determined by Vendor
Vibration Random	Linear increase from .02 g^2cps to .07 g^2/cps Constant .07 g^2/cps	15-100 cps 100-550 cps	Sinusoidal vibration shall be superimposed on the random vibration. Random vibration shall be 20 minutes for each of the three mutually perpendicular axes for a total time of 60 minutes
	Linear decrease from .07 g^2/cps to .05 g^2/cps	550-2000 cps	
Sinusoidal	Constant Velocity 1.3 in/sec Constant 7.0 g	5-330 cps 330-2000 cps	Sinusoidal vibration shall be 10 minutes fo for each of the three mutuall perpendicular axes for a total time of 30 minutes. The frequency shall be swept logarithmically in 5 minutes
Operating of PTCS			Vibration due to operation of PTCS to be supplied by the Vendor
Shock (landing)			To be supplied by Grumman
Sand and Dust			
Thrust Chamber Cluster			To be supplied by Grumman

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TABLE VI - (CONTINUED)

Test Description	Intensity or Rate	Cycles or Time	Remarks
(e) Lunar Stay Temperature Tanks and Components Thrust Chamber Clusters	$+25^{\circ}F$ to $115^{\circ}F$ Solar flux 440BTU/ft^2 hr Lunar Surface $-300^{\circ}F$ to $+250^{\circ}F$ Space $-460^{\circ}F$	24 hours	Temperature due to combined exposure of solar flux, lunar surface and space shall be determined by Vendor.

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TABLE VII

Visual Mgntude	Mass Slugs	Mass Grams	Diameter* Microns	Diameter Inches	Daily Accretion of Earth	Velocity KM/sec.	Velocity ft/sec.
0	$1.71x10^{-4}$	2.5	11,070	.435	$3.3x10^{5}$	28	91,900
1	$6.82x10^{-5}$	$9.95x10^{-1}$	8.160	.320	$1.225x10^{6}$	28	91,900
2	$2.71x10^{-5}$	$3.96x10^{-1}$	6,000	.236	$4.55x10^{6}$	28	91,900
3	$1.08x10^{-5}$	$1.58x10^{-1}$	4,410	.173	$1.69x10^{7}$	28	91,900
4	$4.30x10^{-6}$	$6.28x10^{-2}$	3,250	.127	$6.27x10^{7}$	28	91,900
5	$1.71x10^{-6}$	$2.50x10^{-2}$	2,390	$9.36x10^{-2}$	$2.33x10^{8}$	28	91,900
6	$6.82x10^{-7}$	$9.95x10^{-3}$	1.760	$6.91x10^{-2}$	$5.84x10^{8}$	28	91,900
7	$2.71x10^{-7}$	$3.96x10^{-3}$	1.290	$5.07x10^{-2}$	$1.47x10^{9}$	28	91,900
8	$1.08x10^{-7}$	$1.58x10^{-3}$	951	$3.74x10^{-2}$	$3.69x10^{9}$	27	88,600
9	$4.30x10^{-8}$	$6.28x10^{-4}$	700	$2.75x10^{-2}$	$0.26x10^{9}$	26	85,300
10	$1.71x10^{-8}$	$2.50x10^{-4}$	514	$2.02x10^{-2}$	$2.33x10^{10}$	25	82,000
11	$6.82x10^{-9}$	$9.95x10^{-5}$	379	$1.49x10^{-2}$	$5.84x10^{10}$	24	78,700
12	$2.71x10^{-9}$	$2.96x10^{-5}$	279	$1.09x10^{-2}$	$1.47x10^{11}$	23	75,500
13	$1.08x10^{-9}$	$1.58x10^{-5}$	205	$8.04x10^{-3}$	$3.69x10^{11}$	22	72,200
14	$4.30x10^{-10}$	$6.28x10^{-6}$	151	$5.93x10^{-3}$	$9.26x10^{11}$	21	68,900
15	$1.71x10^{-10}$	$2.50x10^{-6}$	111	$4.35x10^{-3}$	$2.33x10^{12}$	20	65,600
16	$6.28x10^{-11}$	$9.95x10^{-7}$	81.6	$3.20x10^{-3}$	$5.84x10^{12}$	19	62,300
17	$2.71x10^{-11}$	$3.96x10^{-7}$	60	$2.36x10^{-2}$	$1.47x10^{13}$	18	59,100
18	$1.08x10^{-12}$	$1.58x10^{-7}$	44.1	$1.73x10^{-3}$	$3.69x10^{13}$	17	55,800
19	$4.30x10^{-12}$	$6.28x10^{-8}$	32.5	$1.27x10^{-3}$	$9.26x10^{13}$	16	52,500
20	$1.71x10^{-13}$	$2.50x10^{-8}$	23.9	$9.36x10^{-4}$	$2.33x10^{14}$	15	49,200
21	$6.82x10^{-13}$	$9.95x10^{-9}$	17.6	$6.91x10^{-4}$	$5.84x10^{14}$	15	49,200
22	$2.71x10^{-13}$	$3.96x10^{-9}$	12.9	$5.07x10^{-4}$	$1.47x10^{15}$	15	49,200
23	$1.08x10^{-13}$	$1.58x10^{-9}$	9.5	$3.74x10^{-4}$	$3.69x10^{15}$	15	49,200
24	$4.30x10^{-14}$	$6.28x10^{-10}$	7.00	$2.75x10^{-4}$	$9.26x10^{15}$	15	49,200
25	$1.71x10^{-14}$	$2.50x10^{-10}$	5.14	$2.02x10^{-4}$	$2.33x10^{16}$	15	49,200

Whipple's distribution for sporadic meteoroids

*Diameters based on ρ =3.5 m grams/cc.

TABLE VIII

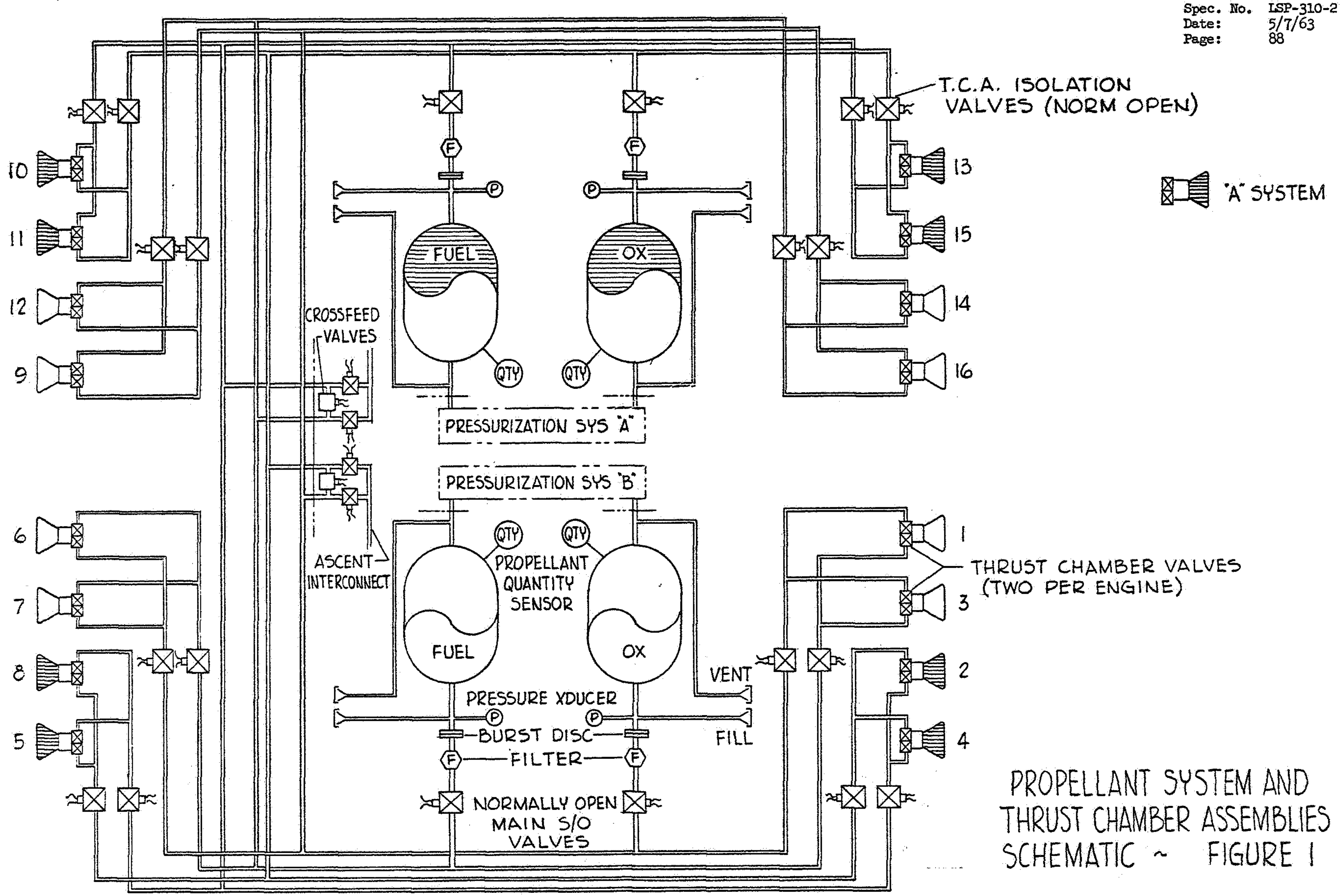
ACCEPTANCE TEST CONDITIONS

To be supplied at a later date

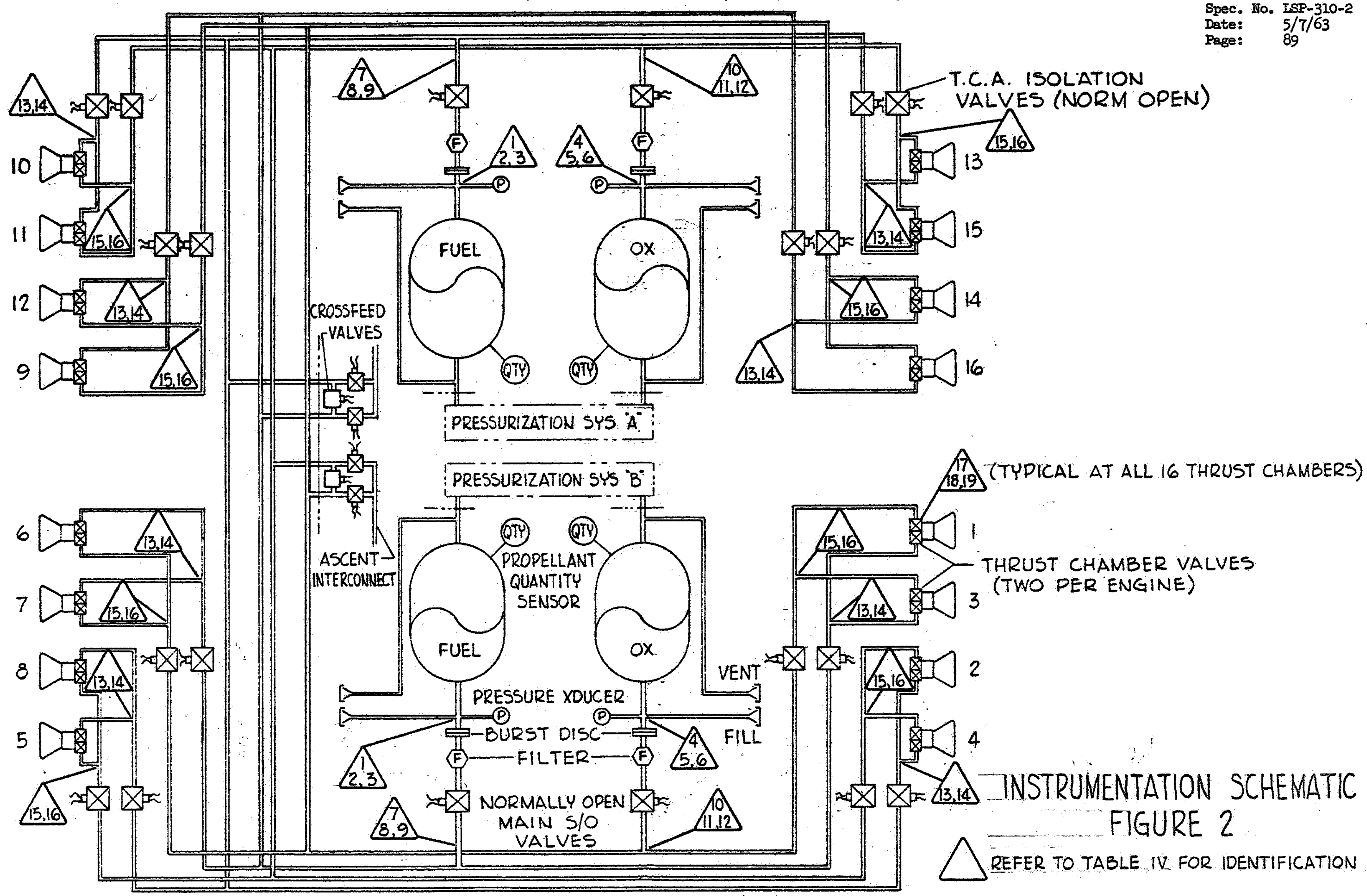
TABLE IX

WEIGHTS FOR THE PROPELLANT SYSTEM AND THRUST CHAMBER ASSEMBLIES

Item			Weight
Propellant Tanks(4)			34.8 lbs.
Plumbing			29.8 lbs.
Fuel System Valves and Lines	-	6.9	
Oxidizer System Valves and Lines	-	6.9	
Thruster Isolation Valves	-	16.0	
Thrust Chamber Cluster Assembly (4) (16 lb/ass'y)			64.0 lbs.
		Total	128.6 lbs.

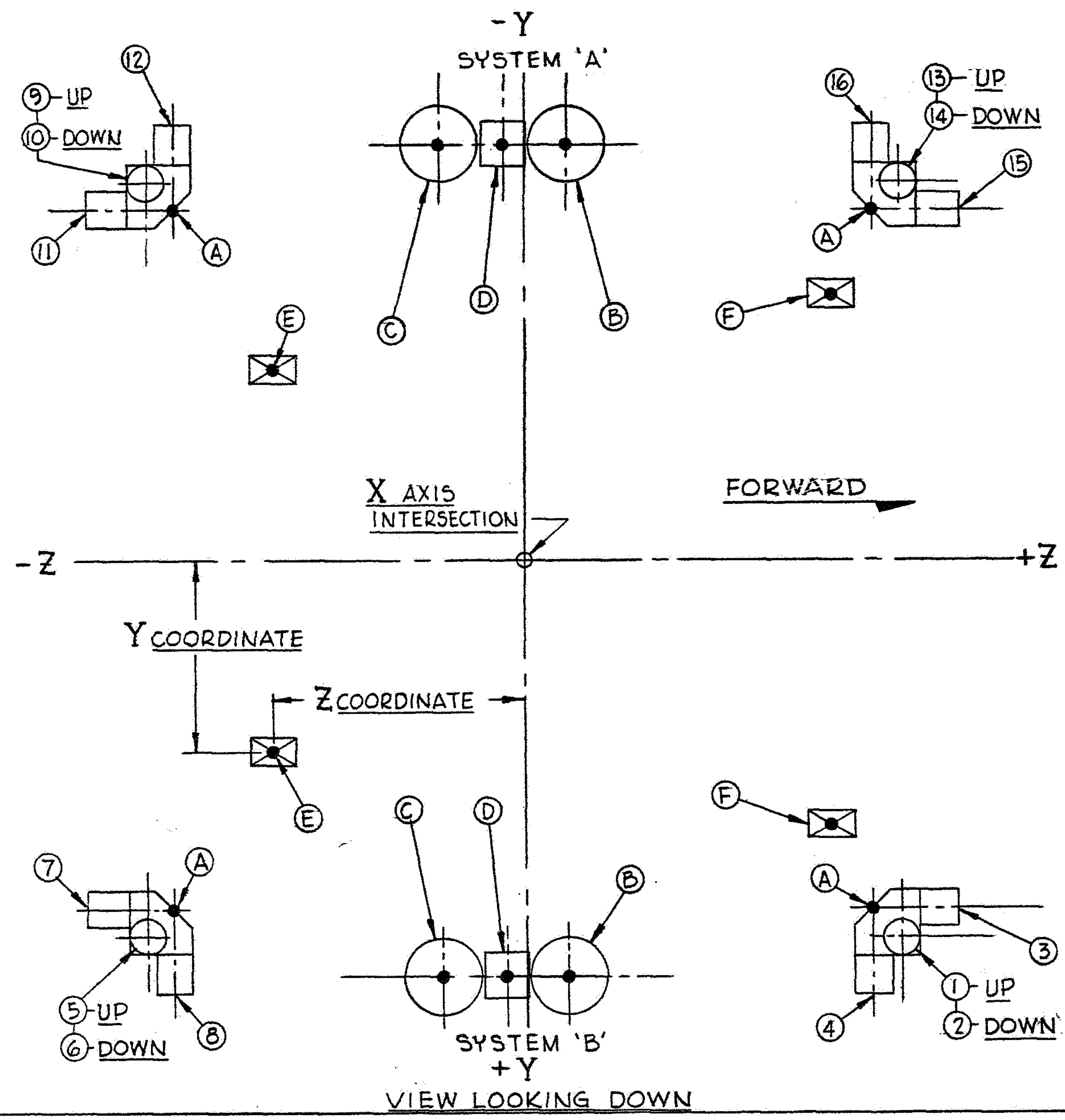


PROPELLANT SYSTEM AND THRUST CHAMBER ASSEMBLIES SCHEMATIC ~ FIGURE 1



INSTRUMENTATION SCHEMATIC
FIGURE 2

△ REFER TO TABLE IV FOR IDENTIFICATION



POINT	COMPONENT	COORDINATES - Y -	- Z -
A	T.C.A. CLUSTER	± 61.5	± 61.5
B	OXID. TANK	± 73.0	+ 7.0
C	FUEL TANK	± 73.0	- 14.0
D	MAIN VALVES	± 73.0	- 3.5
E	T.C.A. ISOLATION VALVES	± 33.0	- 44.0
F	T.C.A. ISOLATION VALVES	± 46.0	+ 54.0

PROPELLANT SYSTEM AND
THRUST CHAMBER ASSEMBLIES
COMPONENT LOCATIONS
FIGURE 3

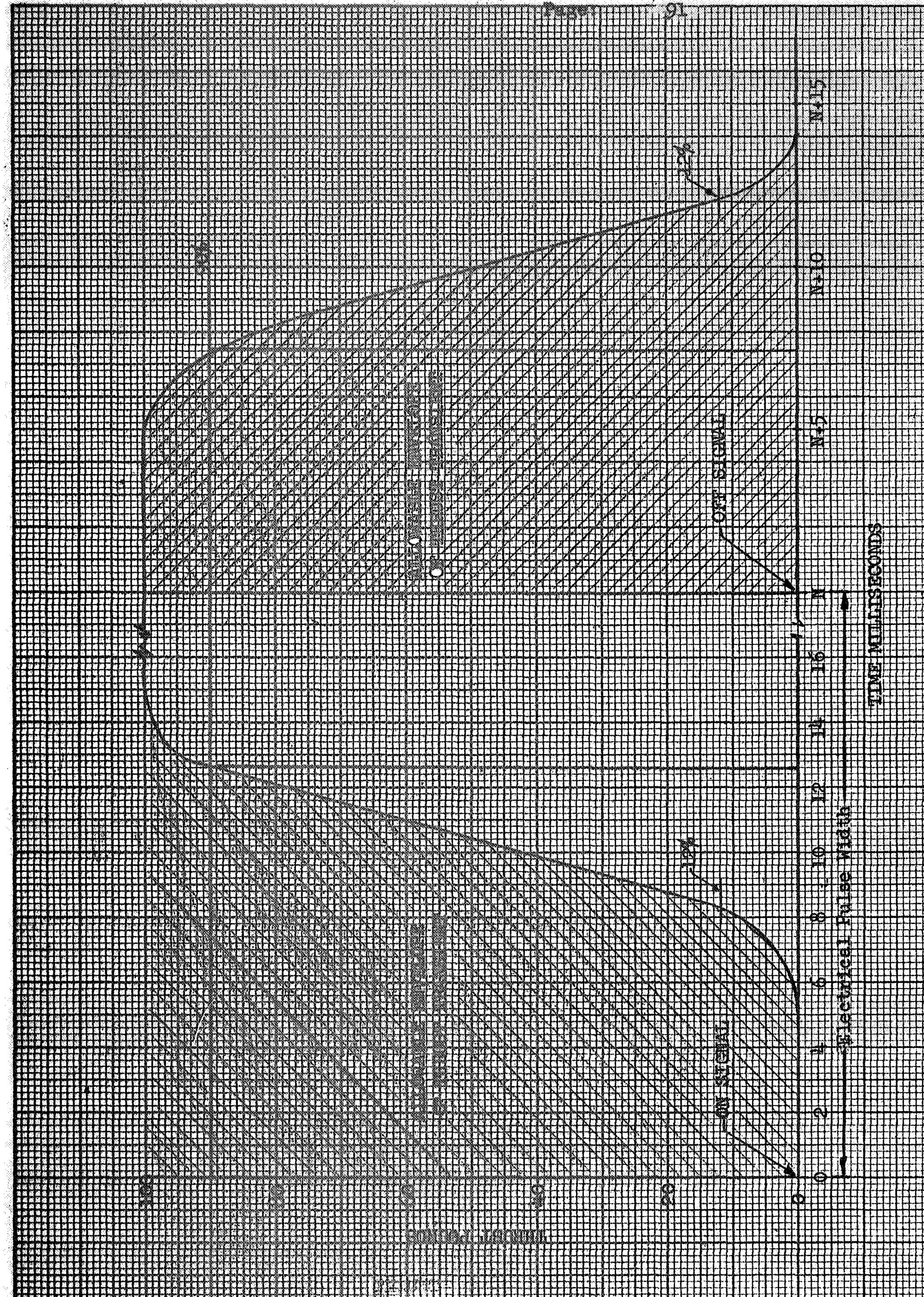
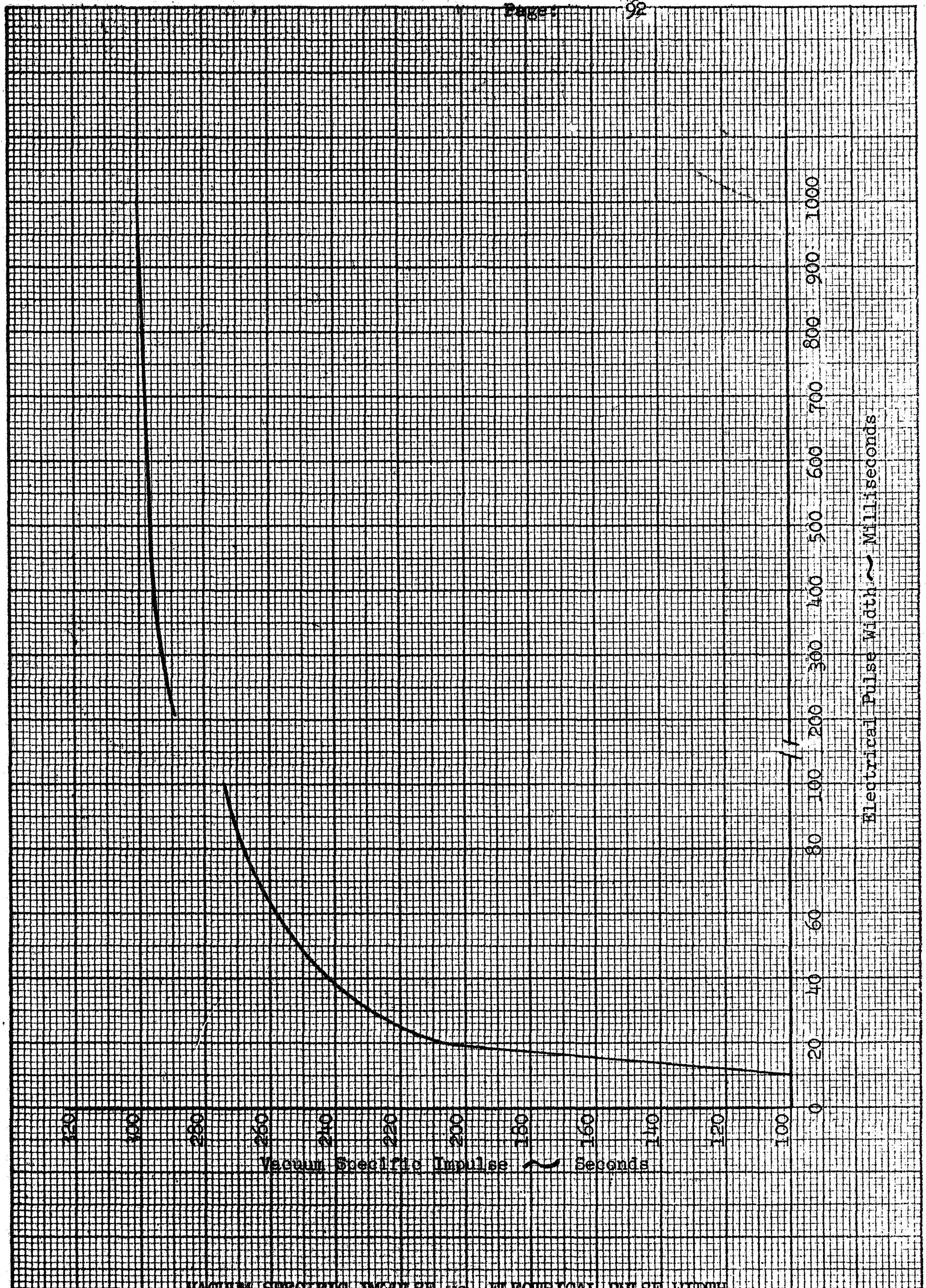

ON SIGNAL
OFF SIGNAL
Electrical Pulse Width
TIME MILLISECONDS
0
2
4
6
8
10
12
14
16
N
N+5
N+10
N+15
0
20
40
60
80
100

FIGURE 4



VACUUM SPECIFIC IMPULSE vs. ELECTRICAL PULSE WIDTH

FIGURE 5

CHANGE LETTER	CHANGE NO.	DESCRIPTION OF CHANGE AND REASON	CHANGED BY AND DATE	ENGRG APPD	NASA. APPD

The Propellant System and Thrust Chamber Assemblies (PS/TCA) of the Reaction Control System shall consist of the following components:

Drawing No.	Qty. Reqd.	Title
LSC-310-111	2	Tank, Oxidizer, Positive Expulsion
LSC-310-112	2	Tank, Fuel, Positive Expulsion
LSC-310-113	2	Components, Oxidizer Feed
LSC-310-114	2	Components, Fuel Feed
LSC-310-115	4	Valve Assembly, T.C.A. Isolation
LSC-310-116	4	Thrust Chamber Cluster Assembly
LSC-310-117	2	Coupling, Oxidizer Tank, Fill & Drain Disconnect
LSC-310-118	2	Coupling, Oxidizer Tank, Fill-Vent Disconnect
LSC-310-119	2	Coupling, Fuel Tank, Fill & Drain Disconnect
LSC-310-120	2	Coupling, Fuel Tank, Fill-Vent Disconnect

FIGURE 6

SPECIFICATION CONTROL DRAWING

THIS DRAWING FORMS A PART OF LSP310-2 CONTROL SPEC.

DEPT	CODE	SIGNATURE
DRAWN	310	A. Small
CHECKED	310	[illegible]
SUBSYSTEM	310	[illegible]
STRUCTURES	520	[illegible]
WEIGHTS	490	
VEH DES & INT	280	[illegible]
SYSTEM CORD	540	[illegible]
SPECIF	14	[illegible]
SS PROJ ENGR	280	[illegible]

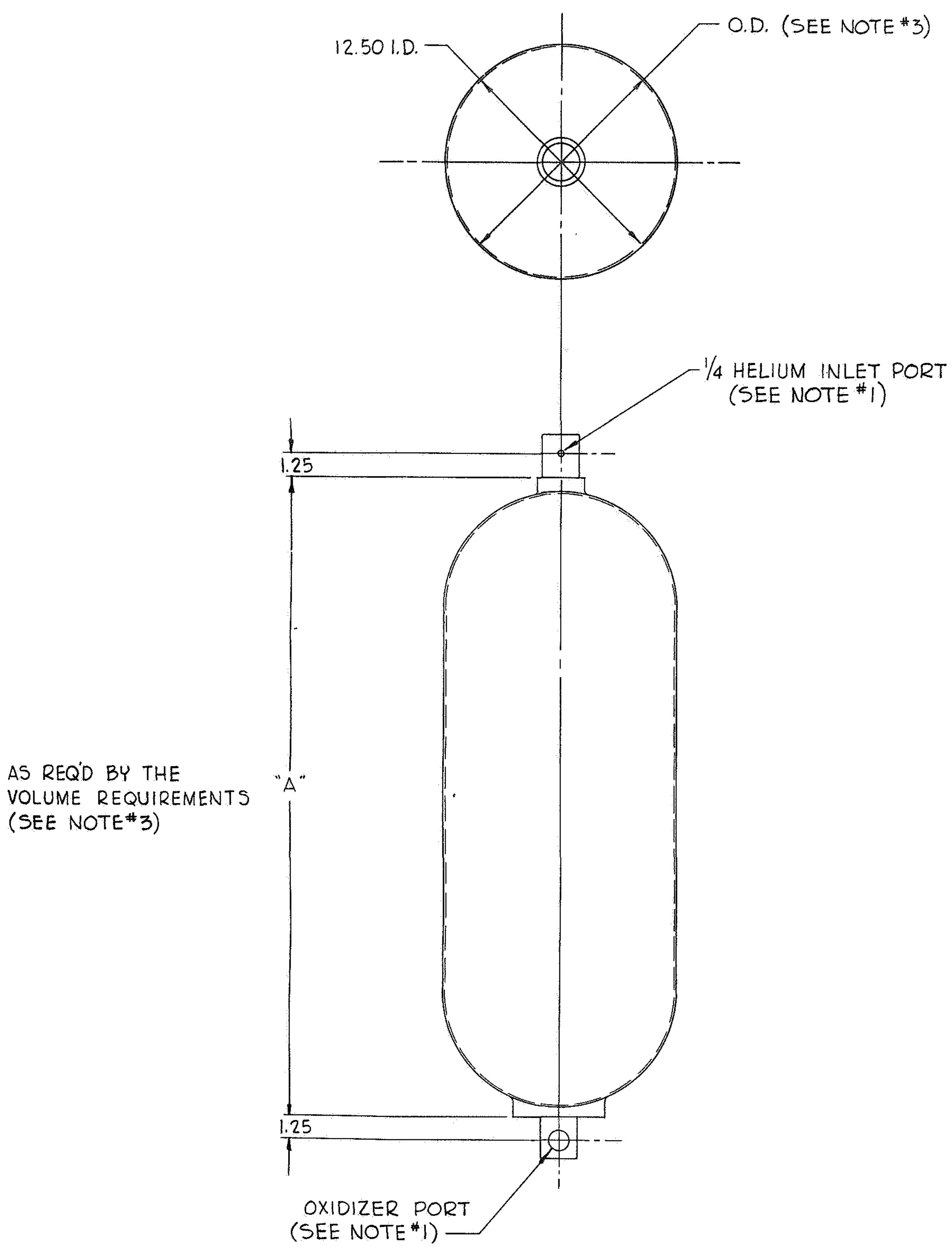
GRUMMAN AIRCRAFT ENGRG CORP
BETHPAGE, L.I. N.Y.

COMPONENTS LIST
RCS - Propellant System and Thrust Chamber Assemblies

CONTRACT NO.

CODE IDENT NO.	SIZE	
26512	B	LSC- 310-100

SCALE NONE | WEIGHT | SHEET



NOTES:
1. TENTATIVE PORT REQ'MTS NOTED. CONFIGURATION OF PORTS SHALL BE SPECIFIED AT A LATER DATE.
2. TANKS SHALL BE TRUNNION MOUNTED AT EACH END.
3. ADDITIONAL DIMENSIONS WILL BE SUPPLIED AT A LATER DATE.
4. THE DIMENSIONS SHOWN ESTABLISH MAXIMUM ENVELOPE REQUIREMENTS.
5. THE ACTUAL DRY WEIGHT AND C.G. LOCATION SHALL BE NOTED WHEN ESTABLISHED.
6. ALL DIMENSIONS ARE GIVEN IN INCHES. SPECIFIC TOLERANCES WILL BE NOTED WHEN ESTABLISHED.

CHANGE LETTER	CHANGE NO.	DESCRIPTION OF CHANGE AND REASON	CHANGE BY AND DATE	ENGRG APPD	NASA APPD

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SPECIFICATION CONTROL DRAWING
THIS DRAWING FORMS A PART OF LSP-310-2 CONTROL SPEC.

DEPT	CODE	SIGNATURE
DRAWN	310	E.L. KLEIN
CHECKED	310	R. Hageman
SUBSYSTEM	310	[illegible]
STRUCTURES	520	[illegible]
WEIGHTS	490	[illegible]
VEH DES & INT	280	[illegible]
SYSTEM CORD	520	[illegible]
SPECIF	14	[illegible]
SS PROJ ENGR	260	[illegible]

GRUMMAN AIRCRAFT ENGRG CORP
BETHPAGE, L. I., N. Y.

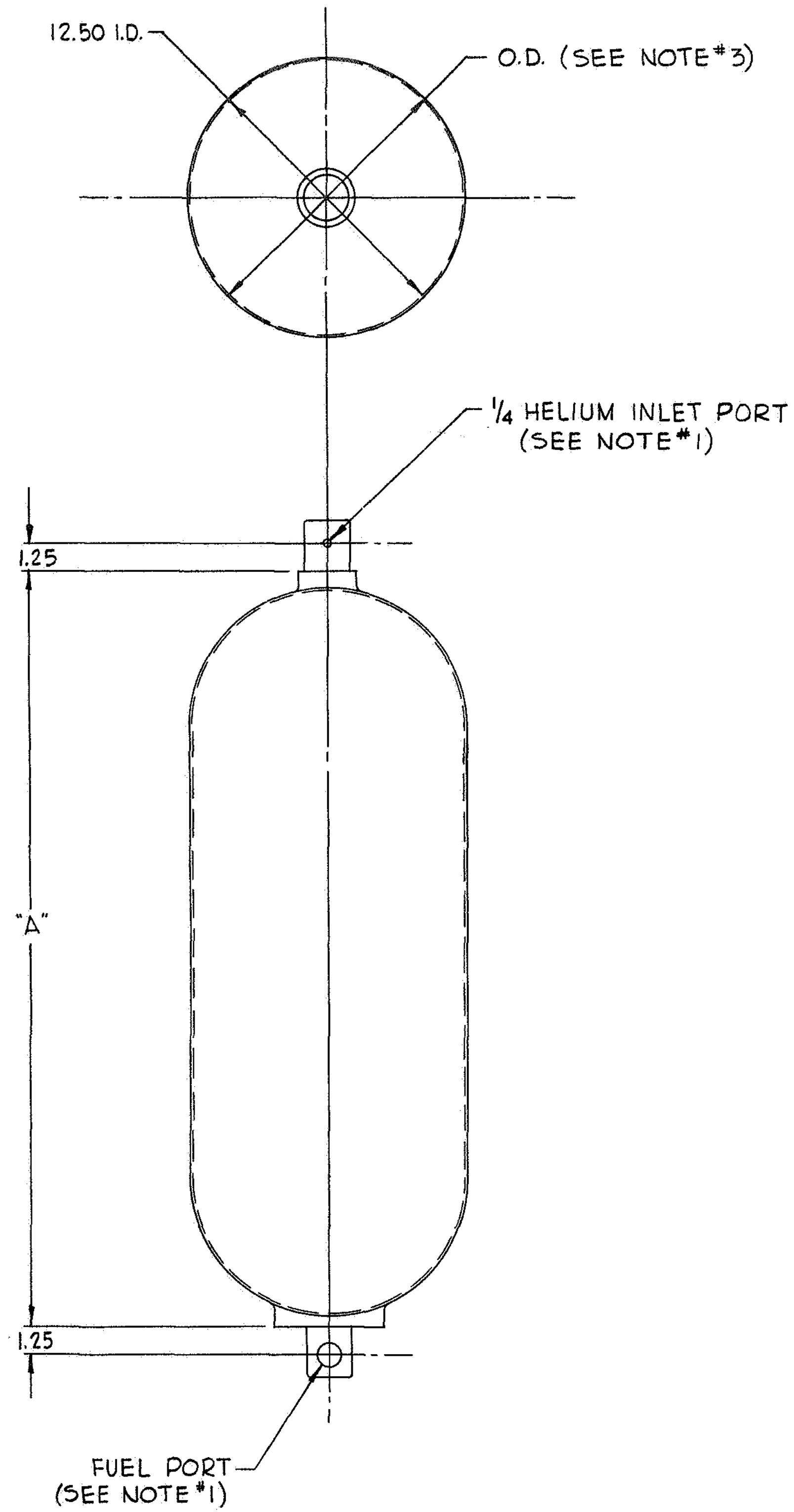
TANK
R.C.S.- POSITIVE EXPULSION- OXIDIZER

CONTRACT NO.

CODE IDENT NO.	SIZE	
26512	D	LSC-310-111
SCALE 1/4 : 1	WEIGHT	SHEET

CHANGE LETTER	CHANGE NO.	DESCRIPTION OF CHANGE AND REASON	CHANGE BY AND DATE	ENGRG APPD	NASA APPD

NOTES:
1. TENTATIVE PORT REQ'MTS NOTED. CONFIGURATION OF PORTS SHALL BE SPECIFIED AT A LATER DATE.
2. TANKS SHALL BE TRUNNION MOUNTED AT EACH END.
3. ADDITIONAL DIMENSIONS WILL BE SUPPLIED AT A LATER DATE.
4. THE DIMENSIONS SHOWN ESTABLISH MAXIMUM ENVELOPE REQUIREMENTS.
5. THE ACTUAL DRY WEIGHT AND C.G. LOCATION SHALL BE NOTED WHEN ESTABLISHED.
6. ALL DIMENSIONS ARE GIVEN IN INCHES. SPECIFIC TOLERANCES WILL BE NOTED WHEN ESTABLISHED.



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SPECIFICATION CONTROL DRAWING
THIS DRAWING FORMS A PART OF
LSP-310-2 CONTROL SPEC.

DEPT	CODE	SIGNATURE
DRAWN	310	E.L.KLEIN
CHECKED	310	[illegible]
SUBSYSTEM	310	[illegible]
STRUCTURES	520	[illegible]
WEIGHTS	490	[illegible]
VEH DES & INT	280	[illegible]
SYSTEM CORD	520	[illegible]
SPECIF	14	[illegible]
SS PROJ ENGR	260	[illegible]

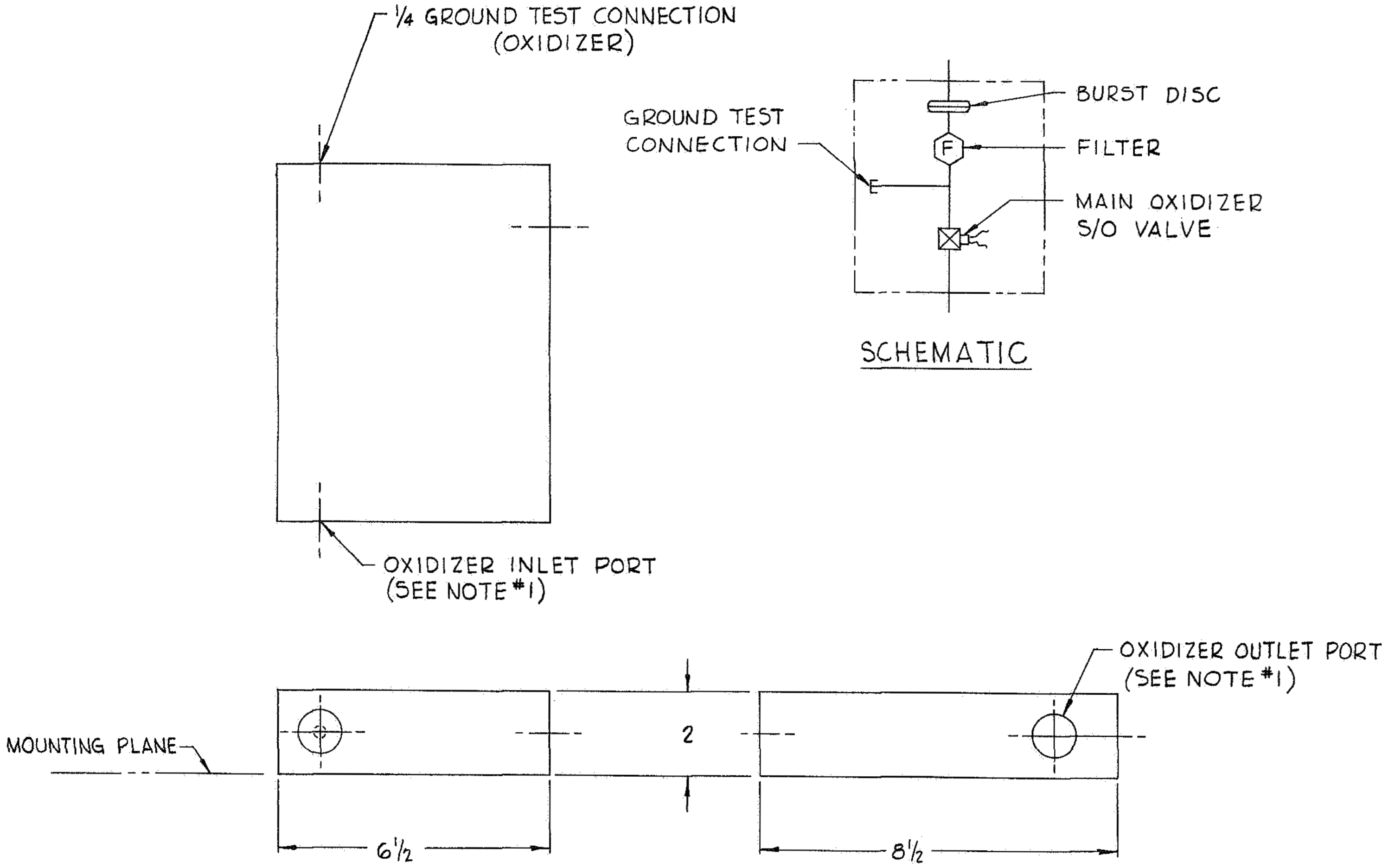
GRUMMAN AIRCRAFT ENGRG CORP
BETHPAGE, L. I., N. Y.

TANK
R.C.S.-POSITIVE EXPULSION- FUEL

CONTRACT NO.		
CODE IDENT NO. 26512	SIZE D	LSC-310-112
SCALE 1/4 : 1	WEIGHT	SHEET

CHANGE LETTER	CHANGE NO.	DESCRIPTION OF CHANGE AND REASON	CHANGED BY AND DATE	ENGRG APPD	NASA APPD

NOTES:
1. TENTATIVE PORT REQ'MTS NOTED. CONFIGURATION OF PORTS SHALL BE SPECIFIED AT A LATER DATE.
2. ELECTRICAL CONNECTIONS SHALL BE SPECIFIED AT A LATER DATE.
3. THE DIMENSIONS SHOWN ESTABLISH THE MAXIMUM ENVELOPE REQUIREMENTS.
4. THE ACTUAL DRY WEIGHT AND C.G. LOCATION SHALL BE NOTED WHEN ESTABLISHED.
5. ALL DIMENSIONS ARE GIVEN IN INCHES. SPECIFIC TOLERANCES WILL BE NOTED WHEN ESTABLISHED.



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SPECIFICATION CONTROL DRAWING
THIS DRAWING FORMS A PART OF LSP-310-2 CONTROL SPEC.

DEPT	CODE	SIGNATURE
DRAWN	310	E.L.KLEIN
CHECKED	310	[illegible]
SUBSYSTEM	310	[illegible]
STRUCTURES	520	[illegible]
WEIGHTS	490	[illegible]
VEH DES & INT	280	[illegible]
SYSTEM CORD	520	[illegible]
SPECIF	14	[illegible]
SS PROJ ENGR	260	[illegible]

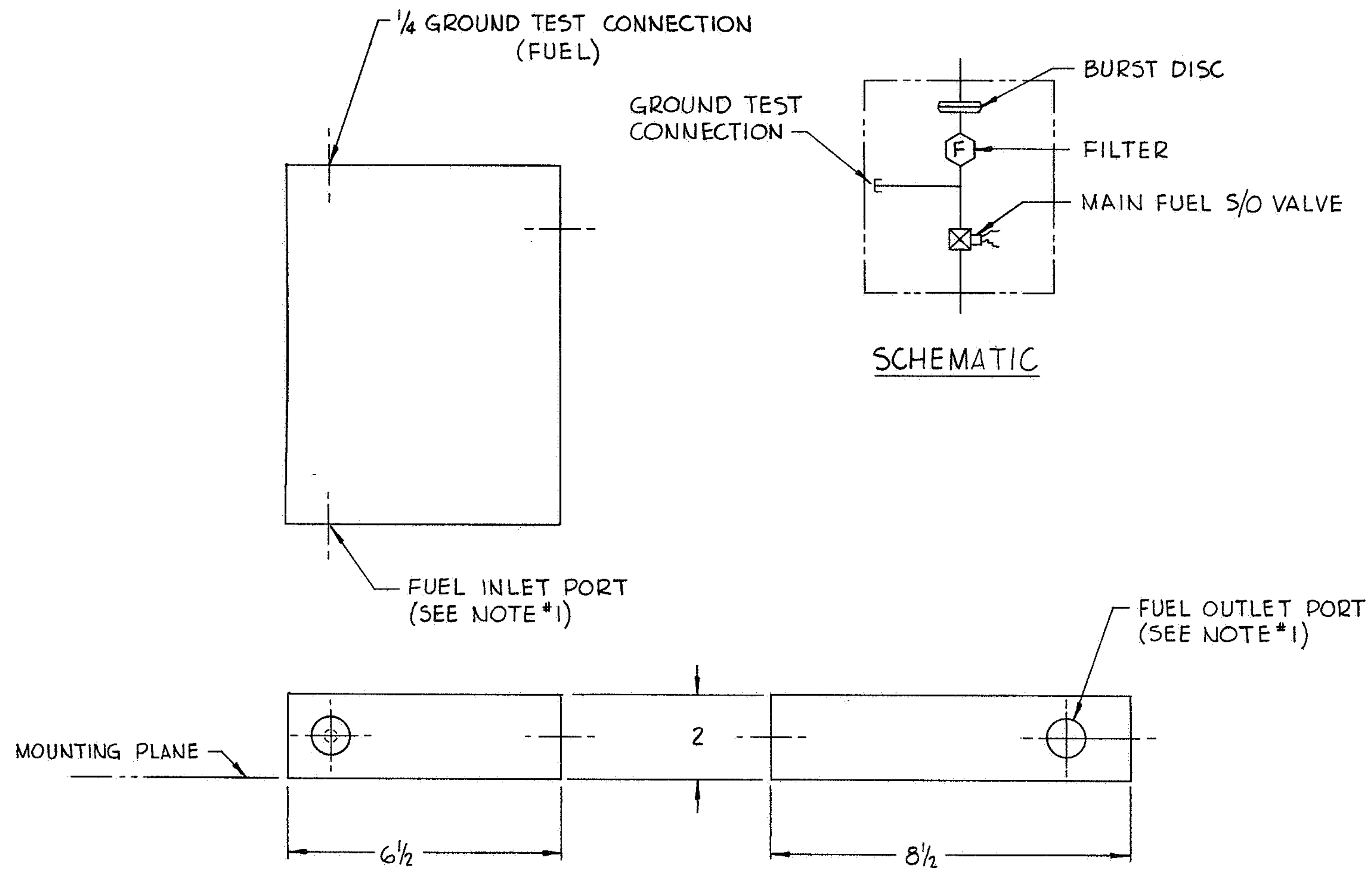
GRUMMAN AIRCRAFT ENGRG CORP
BETHPAGE, L. I., N. Y.

COMPONENTS
R.C.S. OXIDIZER FEED

CONTRACT NO.
CODE IDENT NO. 26512 | SIZE D 22x34 | LSC-310-113
SCALE 1/2:1 | WEIGHT | SHEET

CHANGE LETTER	CHANGE NO.	DESCRIPTION OF CHANGE AND REASON	CHANGED BY AND DATE	ENGRG APPD	NASA APPD

NOTES:
1. TENTATIVE PORT REQ'MTS NOTED. CONFIGURATION OF PORTS SHALL BE SPECIFIED AT A LATER DATE.
2. ELECTRICAL CONNECTIONS SHALL BE SPECIFIED AT A LATER DATE.
3. THE DIMENSIONS SHOWN ESTABLISH THE MAXIMUM ENVELOPE REQUIREMENTS.
4. THE ACTUAL DRY WEIGHT AND C.G LOCATION SHALL BE NOTED WHEN ESTABLISHED.
5. ALL DIMENSIONS ARE GIVEN IN INCHES. SPECIFIC TOLERANCES WILL BE NOTED WHEN ESTABLISHED.



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SPECIFICATION CONTROL DRAWING
THIS DRAWING FORMS A PART OF LSP-310-2 CONTROL SPEC.

DEPT.	CODE	SIGNATURE
DRAWN	310	E.L. KLEIN
CHECKED	310	R. Hageman
SUBSYSTEM	310	[illegible]
STRUCTURES	520	[illegible]
WEIGHTS	490	J.C. Salina
VEH DES & INT	280	[illegible]
SYSTEM CORD	520	[illegible]
SPECIF	14	E. Bernstein
S.S. PROJ ENGR	260	[illegible]

GRUMMAN AIRCRAFT ENGRG CORP
BETHPAGE, L. I., N. Y.

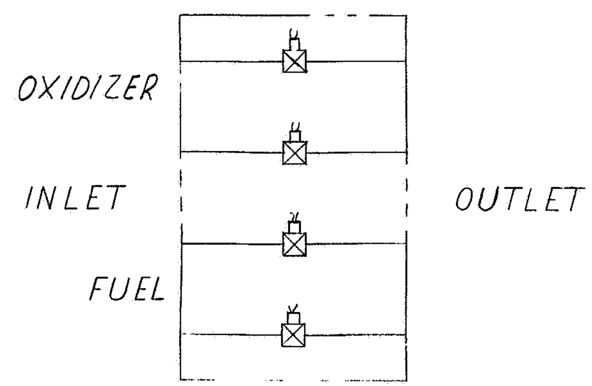
COMPONENTS
R.C.S. FUEL FEED

CONTRACT NO.

CODE IDENT NO.	SIZE	
26512	D 22x34	LSC-310-114
SCALE 1/2:1	WEIGHT	SHEET

CHANGE LETTER	CHANGE NO.	DESCRIPTION OF CHANGE AND REASON	CHANGED BY AND DATE	ENGR APPD	NASA APPD

SCHEMATIC



NOTES.

1. CONFIGURATION REQ'MTS TO BE SPECIFIED AT A LATER DATE.
2. PROVIDE CLEARANCE ON ALL INLET AND OUTLET PORTS FOR COUPLING DEVICE. TO BE SPECIFIED AT A LATER DATE.
3. THE DIMENSIONS SHOWN ESTABLISH THE MAXIMUM ENVELOPE REQUIREMENTS.
4. THE ACTUAL DRY WEIGHT AND C.G. LOCATION SHALL BE NOTED WHEN SPECIFIED.
5. ALL DIMENSIONS GIVEN IN INCHES. SPECIFIC TOLERANCES WILL BE NOTED WHEN ESTABLISHED.

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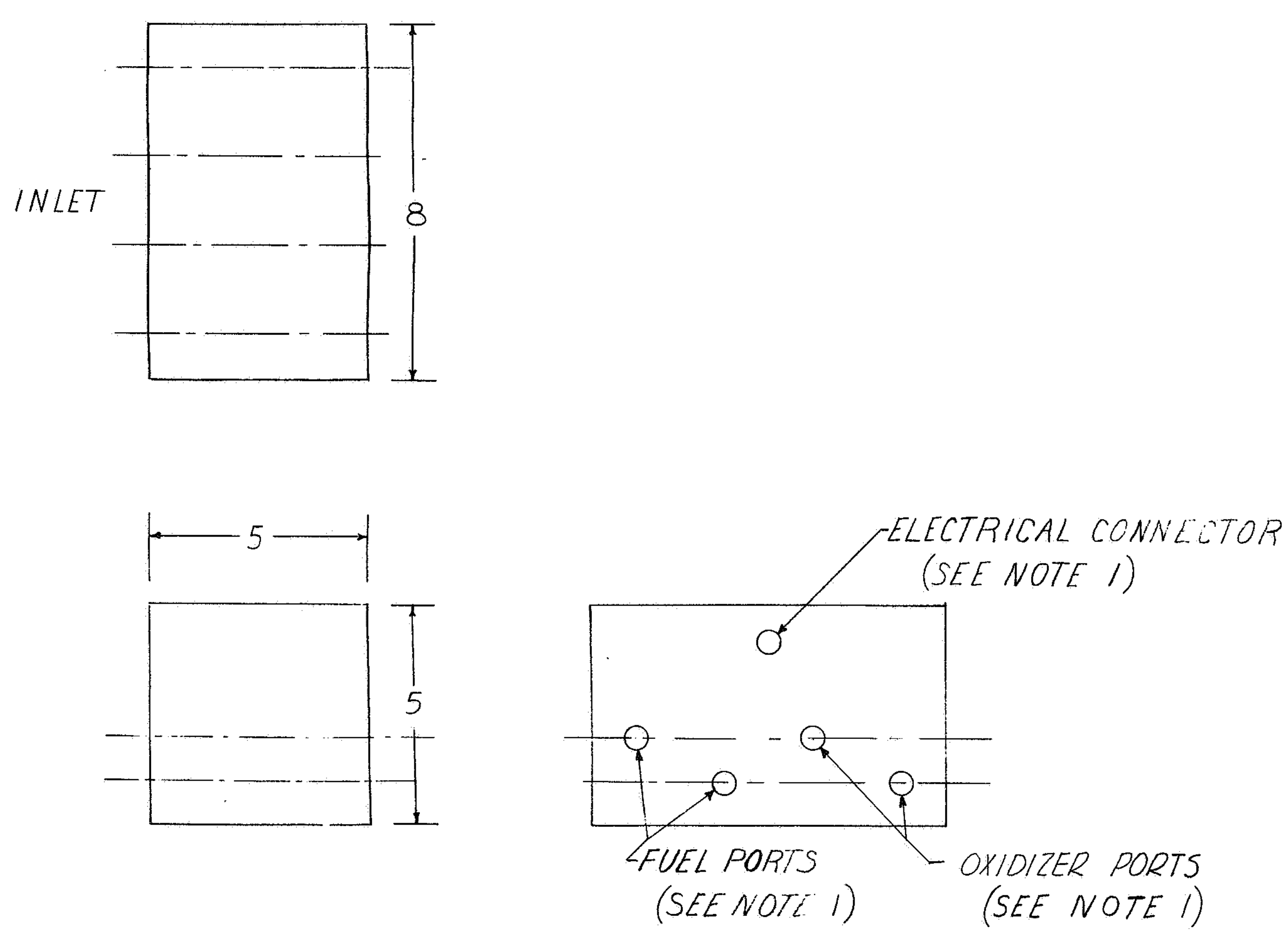

CONFIDENTIAL

SPECIFICATION CONTROL DRAWING
THIS DRAWING FORMS A PART OF
LSP-310-2 CONTROL SPEC.

DEPT	CODE	SIGNATURE
DRAWN	310	
CHECKED	310	R. Hagerman
SUBSYSTEM	310	O.S. Williams
STRUCTURE	520	
WEIGHTS	490	
VEH DESIGN	280	
SYSTEM COORD	540	
SPECS	14	R. BERNSTEIN
S.S. PROT ENGR	260	

GRUMMAN AIRCRAFT ENGRG CORP
BETHPAGE, L. I., N. Y.

VALVE ASSEMBLY
R.C.S. THRUST CHAMBER ISOLATION

CONTRACT NO.		
CODE IDENT NO. 26512	SIZE D 22x34	LSC-310-115
SCALE NONE	WEIGHT	SHEET

CHANGE LETTER	CHANGE NO.	DESCRIPTION OF CHANGE AND REASON	CHANGED BY AND DATE	ENGRG APPD	NASA APPD

NOTES:

1. DETAILED HOLE PATTERN & SIZE TO BE SPECIFIED AT A LATER DATE.
2. THE ELECTRICAL CONNECTOR SHALL BE SPECIFIED AND LOCATED AT A LATER DATE.
3. THE PROPELLANT INLET SIZES, LOCATIONS AND FITTINGS SHALL BE SPECIFIED AT A LATER DATE.
4. THE DIMENSIONS SHOWN ESTABLISH THE MAXIMUM ENVELOPE REQUIREMENTS.
5. - THE ACTUAL DRY WEIGHT AND C.G. LOCATION SHALL BE NOTED WHEN ESTABLISHED.
6. - ALL DIMENSIONS GIVEN IN INCHES. SPECIFIC TOLERANCES WILL BE NOTED WHEN ESTABLISHED.
7. - TWO '-1' ASSEMBLIES & TWO '-2' ASSEMBLIES ARE REQUIRED FOR EACH SYSTEM.

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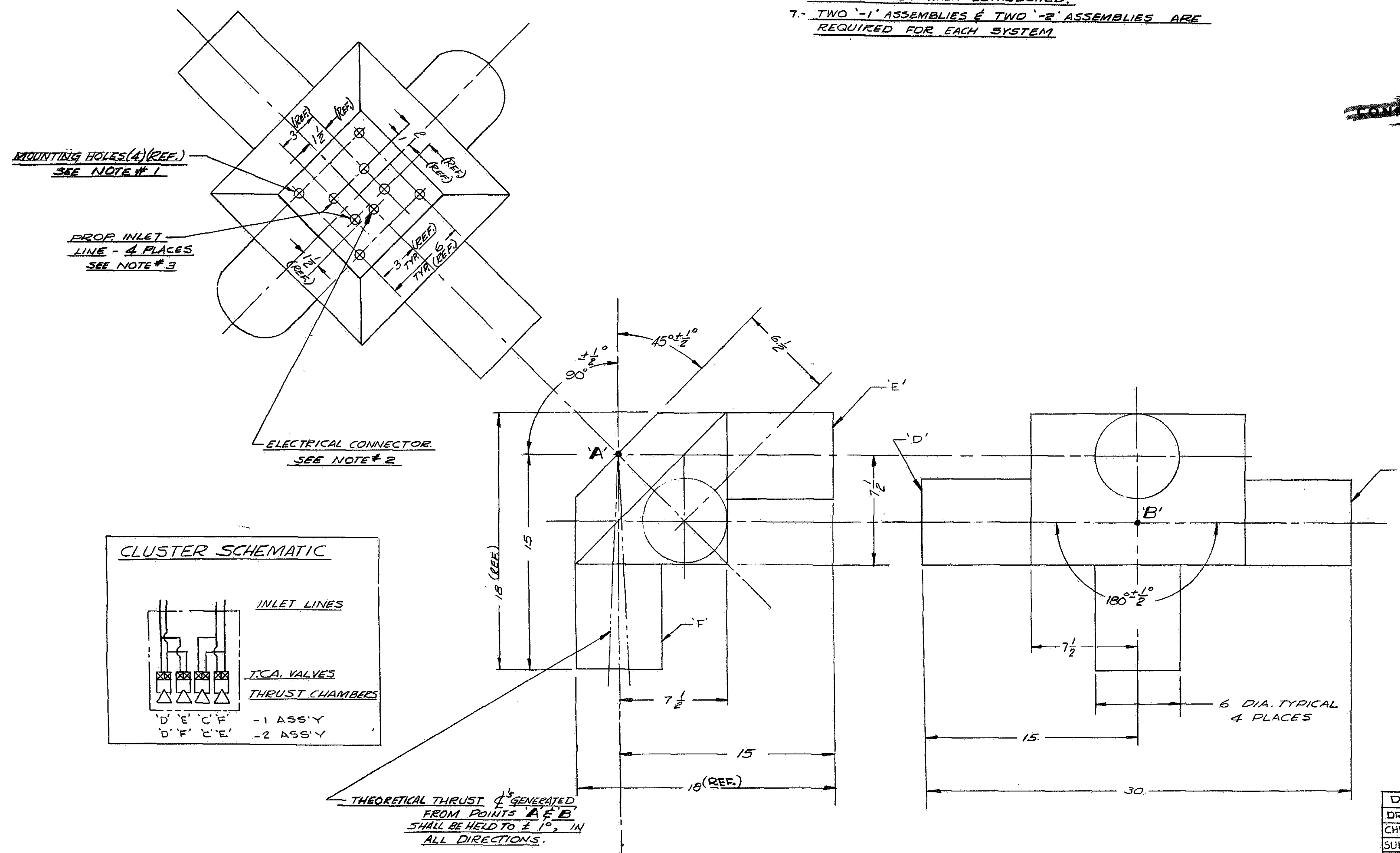

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SPECIFICATION CONTROL DRAWING
THIS DRAWING FORMS A PART OF LSP-310-2 CONTROL SPEC.

DEPT	CODE	SIGNATURE
DRAWN	310	R.W. Houska
CHECKED	31C	R. Hagerman
SUBSYSTEM	310	O.S. William
STRUCTURES	520	[illegible]
WEIGHTS	490	[illegible]
VEH. DES. & INT.	280	[illegible]
SYSTEM CORD	540	[illegible] Smith
SPECIF.	14	[illegible]
S.S. PROJ. ENG	260	McCabee

GRUMMAN AIRCRAFT ENGRG CORP
BETHPAGE, L. I., N. Y.

CLUSTER ASSEMBLY
R.C.S. THRUST CHAMBER

CONTRACT NO.		
CODE IDENT NO. 26512	SIZE D 22x34	LSC-310-116
SCALE 1/4 : 1	WEIGHT	SHEET

CHANGE LETTER	CHANGE NO	DESCRIPTION OF CHANGE AND REASON	CHANGE BY AND DATE	ENGRG APPD	NASA APPD

NOTES:
1. THE DIMENSIONS SHOWN ESTABLISH THE MAXIMUM ENVELOPE REQUIREMENTS.
2. THE ACTUAL DRY WEIGHT AND C.G. LOCATION SHALL BE NOTED WHEN ESTABLISHED.
3. ALL DIMENSIONS ARE GIVEN IN INCHES. SPECIFIC TOLERANCES WILL BE NOTED WHEN ESTABLISHED.

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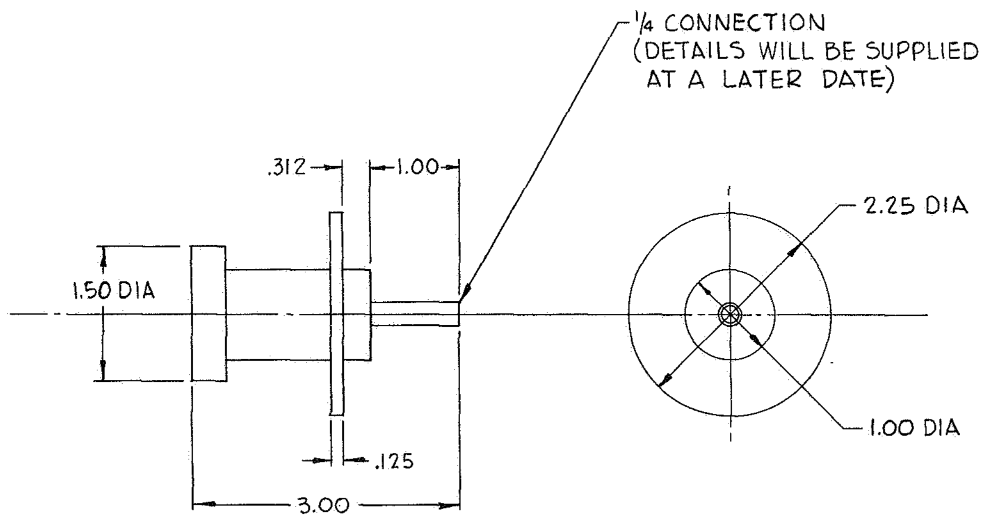

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SPECIFICATION CONTROL DRAWING
THIS DRAWING FORMS A PART OF
LSP-310-2 CONTROL SPEC.

DEPT	CODE	SIGNATURE
DRAWN	310	E.L. KLEIN
CHECKED	310	R. Hagerman
SUBSYSTEM	310	[illegible]
STRUCTURES	520	[illegible]
WEIGHTS	490	[illegible]
VEH DES & INT	280	[illegible]
SYSTEM CORD	520	[illegible]
SPECIF	14	[illegible]
SS PROJ ENGR	260	[illegible]

GRUMMAN AIRCRAFT ENGRG CORP
BETHPAGE, L. I., N. Y.

COUPLING
R.C.S. OXIDIZER TANK-FILL & DRAIN DISCONNECT

CONTRACT NO.

CODE IDENT NO.	SIZE	
26512	D 22x34	LSC-310-117
SCALE FULL	WEIGHT	SHEET

CHANGE LETTER	CHANGE NO.	DESCRIPTION OF CHANGE AND REASON	CHANGED BY AND DATE	ENGRG APPD	NASA APPD

NOTES:
1. THE DIMENSIONS SHOWN ESTABLISH THE MAXIMUM ENVELOPE REQUIREMENTS.
2. THE ACTUAL DRY WEIGHT AND C.G. LOCATION SHALL BE NOTED WHEN ESTABLISHED.
3. ALL DIMENSIONS ARE GIVEN IN INCHES. SPECIFIC TOLERANCES WILL BE NOTED WHEN ESTABLISHED.

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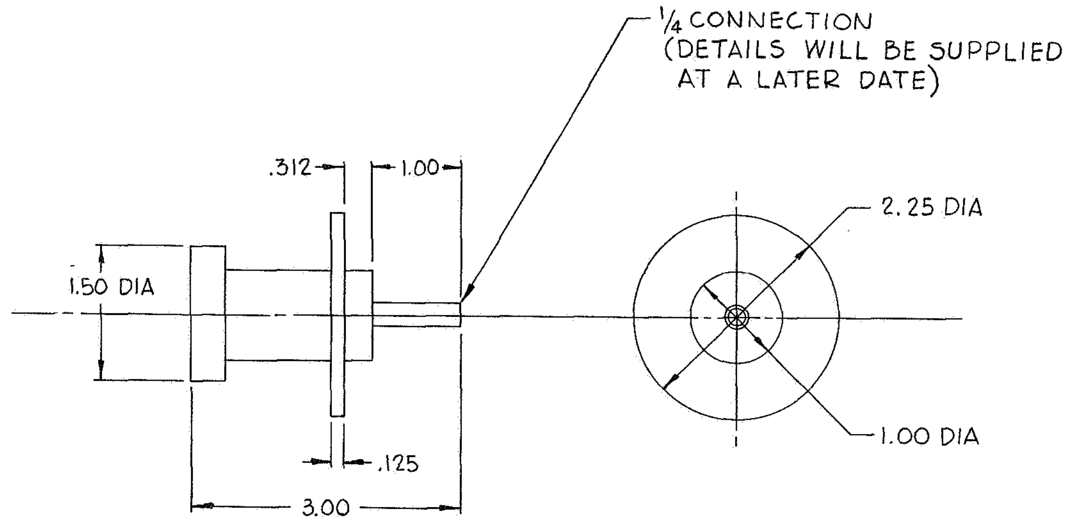

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SPECIFICATION CONTROL DRAWING
THIS DRAWING FORMS A PART OF
LSP-310-2 CONTROL SPEC.

DEPT.	CODE	SIGNATURE
DRAWN	310	E.L.KLEIN
CHECKED	310	[illegible]
SUBSYSTEM	310	[illegible]
STRUCTURES	520	[illegible]
WEIGHTS	490	[illegible]
VEH DES & INT	280	[illegible]
SYSTEM CORD	520	[illegible]
SPECIF	14	[illegible]
S.S. PROJ ENGR	260	[illegible]

GRUMMAN AIRCRAFT ENGRG CORP
BETHPAGE, L. I., N. Y.

COUPLING
R.C.S. OXIDIZER TANK- FILL VENT DISCONNECT

CONTRACT NO.		
CODE IDENT NO. 26512	SIZE D 22×34	LSC-310-118
SCALE FULL	WEIGHT	SHEET

CHANGE LETTER	CHANGE NO.	DESCRIPTION OF CHANGE AND REASON	CHANGED BY AND DATE	ENGRG APPD	NASA APPD

NOTES:
1. THE DIMENSIONS SHOWN ESTABLISH THE MAXIMUM ENVELOPE REQUIREMENTS.
2. THE ACTUAL DRY WEIGHT AND C.G. LOCATION SHALL BE NOTED WHEN ESTABLISHED.
3. ALL DIMENSIONS ARE GIVEN IN INCHES. SPECIFIC TOLERANCES WILL BE NOTED WHEN ESTABLISHED.

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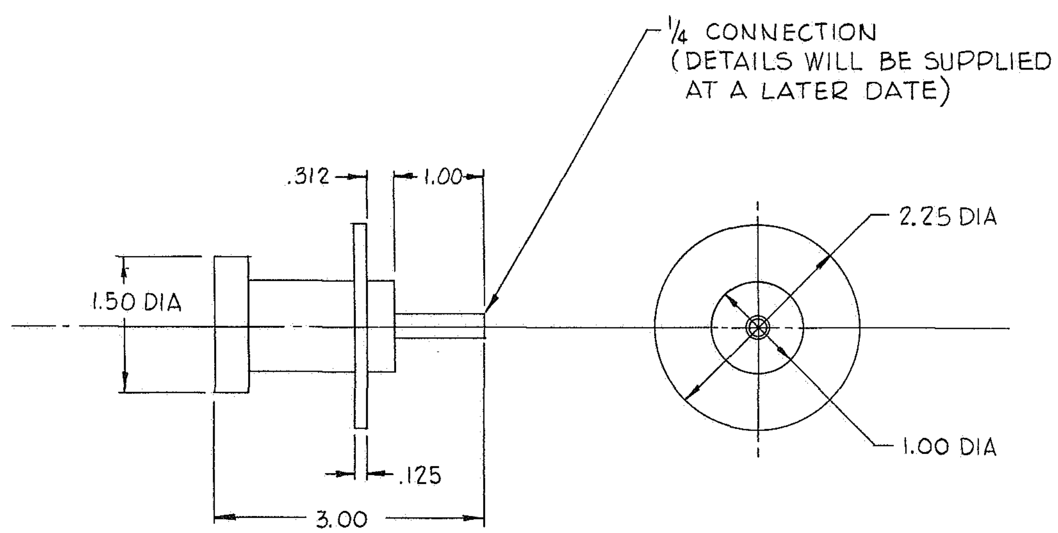

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SPECIFICATION CONTROL DRAWING
THIS DRAWING FORMS A PART OF
LSP-310-2 CONTROL SPEC.

DEPT.	CODE	SIGNATURE
DRAWN	310	E.L. KLEIN
CHECKED	310	R. Hagerman
SUBSYSTEM	310	O.S. Williams
STRUCTURES	520	[illegible]
WEIGHTS	490	J. Cdalma
VEH DES & INT	280	[illegible]
SYSTEM CORD	520	[illegible]
SPECIF	14	R. Bernstein
S.S. PROJ ENGR	260	[illegible]

GRUMMAN AIRCRAFT ENGRG CORP
BETHPAGE, L. I., N. Y.

COUPLING
R.C.S. FUEL TANK-FILL & DRAIN DISCONNECT

CONTRACT NO.

CODE IDENT NO.	SIZE	
26512	D 22×34	LSC 310-119

SCALE FULL | WEIGHT | SHEET

CHANGE LETTER	CHANGE NO.	DESCRIPTION OF CHANGE AND REASON	CHANGED BY AND DATE	ENGRG APPD	NASA APPD

NOTES:
1. THE DIMENSIONS SHOWN ESTABLISH THE MAXIMUM ENVELOPE REQUIREMENTS.
2. THE ACTUAL DRY WEIGHT AND C.G. LOCATION SHALL BE NOTED WHEN ESTABLISHED.
3. ALL DIMENSIONS ARE GIVEN IN INCHES. SPECIFIC TOLERANCES WILL BE NOTED WHEN ESTABLISHED.

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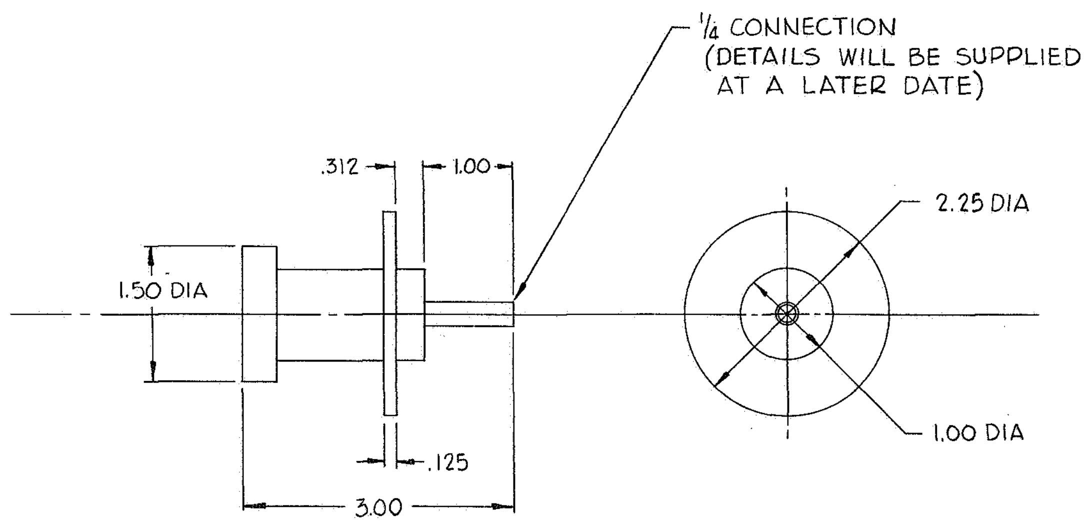

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SPECIFICATION CONTROL DRAWING
THIS DRAWING FORMS A PART OF
LSP-310-2 CONTROL SPEC.

DEPT.	CODE	SIGNATURE
DRAWN	310	E.L. KLEIN
CHECKED	310	[illegible]
SUBSYSTEM	310	[illegible]
STRUCTURES	520	[illegible]
WEIGHTS	490	[illegible]
VEH DES & INT	280	[illegible]
SYSTEM CORD	520	[illegible]
SPECIF	14	R. BERNSTEIN
S.S. PROJ ENGR	260	[illegible]

GRUMMAN AIRCRAFT ENGRG CORP
BETHPAGE, L. I., N. Y.

COUPLING
R.C.S. FUEL TANK-FILL VENT DISCONNECT

CONTRACT NO.

CODE IDENT NO.	SIZE	
26512	D 22x34	LSC-310-120
SCALE FULL	WEIGHT	SHEET